KE Best practice: a short guide for Mathematical Science departments

This document provides a guide to good practice in KE, arising from materials produced by the Big Mathematics Initiative. It has three sections: an overview of the key themes which have consistently emerged; a summary of common points made in the survey of Mathematical Science Departments carried out by the BMI Implementation Committee intended as a source of ideas for other Departments; and a collation of relevant personal experiences of committee members. The aim is not to be prescriptive, but rather to provide a collation of experience from the community to assist Departments in developing their own policies.

1. Broad themes

University mathematical sciences departments engaged in KE tend to have certain features in common which support and enable this.

1. They recognise that mathematical research across all sub-areas of the discipline is potentially impactful, and do not make sharp delineations between areas labelled ‘pure’ and ‘applied’ in this respect.
2. They have mechanisms that support the development and maintenance of new industry collaborations. These will include some sort of contact management, suitable contracts support, resource in terms of academic time and funding, training for staff and students, and connections with other academic disciplines.
3. KE activities are often integrated with undergraduate and MSc teaching, and with PhD training.
4. Knowledge exchange is seen as a worthwhile enterprise for stimulating new research, and as a core part of what a well-rounded mathematical science department should be doing, not merely as money-generating or useful for impact cases.

The Committee received the following example from the Maxwell Institute (Heriot-Watt and Edinburgh Universities), which is quoted in full as an example of what the mathematical sciences might aspire to on scale with a whole industry – this is a kind of large integrated KE activity which is more common in other academic and professional disciplines:

> For instance, in the financial and insurance aspects of the mathematical sciences in the ICMS Bayes Center and Heriot-Watt University and Edinburgh University they have formed a knowledge exchange with Scottish Financial Enterprise know as the Scottish Financial Risk Academy Group. It has a steering committee chaired by the President of the Institute and Faculty of Actuaries, membership of major financial corporations executives such as CEO’s, CRO’s, CTO’s, Partners and Treasures and lead actuaries as well as a variety of academic members. Overall, this opens up a conduit for discussions between mathematics at the level of academics with a collection of 200+ industry members from financial services throughout greater Scotland and the UK, comprising most major asset managers, retail banks, investment banks, hedgefunds, insurers, audit firms, advisory, development banks such as EBRD, SNIB and central banks such as PRA and BOE. The mandate ratified with the SFE board when forming the SFRA Group was to directly facilitate and provide quantitative risk, insurance and financial

mathematics advisory and guidance to inform industry practice and to inform academic progress with real-world practitioner problems and data. Such frameworks may serve as models to facilitate knowledge exchange activities at a variety of levels through colloquia, workshops, bootcamps, sandpits, joint research activities and funded PhD positions, MSc placements and joint training and undergraduate internships.

(BMI, Knowledge Exchange, page 5)

2. Examples from the identified broad themes

This section provides a series of examples from the survey which the BMI carried out, illustrating the four broad themes identified in the opening. These are shortened paraphrases of the original text. Where there are repeated ideas this signifies that more than one institution made essentially the same comment.

All sub-areas are relevant

- As well as collaboration with other disciplines, collaboration between different areas within the mathematical sciences is often crucial for solving real world problems..

Mechanisms to support KE engagement

- Engagement with other University departments through interdisciplinary research centres, joint seminars, joint PhD students etc.
- IIT – Integrative Think Tanks, organized twice a year; bringing academics from various departments & industrial partners together with mathematics PhD students for one week – this produced good value for money through follow-up projects.
- A team of professional mathematical scientists with underwritten salaries, who are available to work part-time and limited periods, has been vital to KE success.
- Long-term relationship with industrial partners through CDT training, CASE awards, etc.
- Participation of staff and students in European Study Groups with Industry.
- Knowledge Transfer Facilitator (KTF) employed on a senior academic-related grade to manage the Knowledge Exchange function
- Network of KTFs, together with other KE stakeholders, including Cambridge Enterprise etc. are meeting regularly for cross-department / University-wide exchange. This network also supports interdisciplinary projects and research proposals.
- Very individualized KE support between appropriate academic and industrial partners is key for successful KE rather than general recipes.
- Anecdotal evidence from individuals about collaborations with other academic disciplines in Durham and internationally.
- Establishing also personal relationships, team building etc. with external researchers.
- Campus city (one month outreach event) – across the whole University.
- What works well is commercially funded research in terms of PDRAs or staff time. This is very rarely consultancy without research focus.
- Offering placements for undergraduate students in businesses or other sectors like scbools; all data science MSc students carry out their master thesis while working in a company; about 10 PhD student placements per year in addition to 20 industrially funded PhD students.
- Good experience with KTPs (good value for money).
- Consultancy, mainly related to data science and statistics; new initiative! CPD courses; sandpit events; KTPs; EPSRC IAA funding.
- Joint seminars have proven to be successful (e.g. Biomaths Colloqium). Joint workshops (standalone meetings) between maths and other departments have not really led to sustainable projects.

- Physical closeness of departments helps with closer interactions. Informal talk series (over lunch and coffee) for exchange within the department or between different departments.
- Secondment of University academics is the main mechanism of KE. Also having “strategic partners” from industry; software engineering team; active international visitor programme; data study groups.
- Model for internal staff of 50% external research and 50% personal research, plus inward secondments at all levels.
- KE officer helps with cross discipline communication, public outreach and industry interactions, event support. Importance of an engaged academic lead on all activities.
- Introduction of “Impact Leave”: at Warwick, academics can apply for a full term of leave to pursue impact activities linked to a potential impact case study. This is independent of the usual Study Leave provision.
- Competitive impact resources at departmental level: academics at Warwick Business School can apply to an internal fund twice per year that supports wider impact activities linked to an impact case study for bids of up to £8,000.
- It is important to have business development and research/academic staff working in a coordinated way, with appropriate division of tasks, to take maximum advantage of opportunities.

Integration with teaching

- Training of undergraduates and research students in KE seems essential. Bath is running several student training programmes with industrial interaction as well as interaction with other academic departments building up a large component. Among this is their industrial placement scheme, the applied MSc and EPSRC CDT and the institute devoted to innovation. In all of those, substantial financial commitment from the University seems crucial (admin & academic FTE; commercial researchers etc). Whether these operations might be self-sustainable at some point from financial return from industry is not clear to me.
- Many undergraduates spend a year on placement in a wide variety of industries. PhD students often spend time (amounting to several months) in industry.
- PhD research projects with industry very successful in building long term relationships
- Undergraduate research placements in industry (CMP (Cambridge Mathematics Placements) programme) to get new companies on board, explore collaborations etc.
- Joint PhD students between industry and academia are crucial.
- One university reports good experience with service teaching for building relationships with other departments.
- Good experience with MSc programmes that involve 3 month placement of students in companies; industrially-university funded PhD students (20% company 80% university). 5 undergraduate students per year are sent into employment for 1 year. However, careful selection of students important due to implications on the programme’s/university’s reputation. Training on responsible data management important – otherwise risk of confidentiality breaches.

- Annual modelling camps at Oxford and ICMS.

A core part of activity

- Explicitly reward contribution to KE in promotion, in workload models etc.
- Research-focused KE activities are a net gain (third-party funding).
- EDI training together with industrial partners.
- The reward for KE in contrast to research paper writing is emphasized.

Challenges

- One constant challenge in KE is to interest academics.
- Problematic / important to change for KE: perception of consultancy (should be assigned with higher esteem factor); visibility of mathematics and its use outside of mathematics.
- Public outreach: costs of staff and student time.
- Statistical consultancy service did not work well (people who are looking for short answers are often not interested in long-term relations).
- Companies need to differentiate between needing "research" and better solving their problem with hiring in-house expertise into the company.

Recommendations

- Recommendations: (1) more financial support for IITs, PostDocs and PhDs; (2) flexible ways of interacting with KE; (3) recognize contribution of KE for academics.
- Recommendations: more financial support; more support with IP questions.
- Recommendations: more funding for externally engaged PhDs and master students; more training of undergraduate students in modelling, computing and writing skills to prepare them for math innovation; also the acknowledgement of math departments for KE (in promotions etc) is a crucial component to make this a successful activity
- Better infrastructure for KE; increase motivation for academics to engage with KE.
- Give academics more time for KE (such as impact leave, for example); support to improve universities' infrastructure for processing contracts etc
- Differentiate between "interesting" industrial collaborations and "free/inexpensive consultancy".
- Higher rewards for KE; more PhD student funding and opportunities.
- Consider creation of departmental impact awards

3. Challenges in Mathematics KE

This section presents a series of reflections on challenges in KE activity and applied funding (which are intimately related). It is based on the 'Knowledge Exchange' report in the first phase of the BMI Implementation Group's activity, which in turn was based on the personal experiences of the committee members who drafted that report (Alan Champneys, Chris Dent, Arne Strauss).

3.1 Issues with culture

The Bond review is clear that there is no distinction between pure and applied mathematics; that all mathematical research is potentially impactful. This is a key message and suggests that all of mathematical science researchers should be thinking about how to move their research along impact pathways and, crucially, to be mindful of mathematical problems that come from further up the pathway towards their area. Some of the very best researchers in mathematics justify their impact (e.g. in EPSRC proposals) via the timescales of impact in pure mathematics, "number theory is important for cryptography, geometry is important for physics, but I doubt any application will occur during the lifetime of this research". There is an inherent 'trickle-down' model of impact; that funding research in pure mathematics will trickle down eventually into applications. This is undoubtedly true on so many levels, not least in term of people impacts.

However, this model fails to acknowledge another pathway; that often pure mathematics arises from impact, e.g. Fourier was trying to understand heat flow in practical problems, Poincaré was trying to understand the stability of the solar system, etc. In other disciplines that have a theoretical core, there is a notion of "T-shaped" people, who do both deep research and have breadth to work outside their discipline. There is sometimes the perception among mathematical scientists that research is a zero-sum game and that if an individual or group engages in such broadening research, then they lose capacity for doing the 'deep stuff'. The mathematical sciences community needs to champion role models among its strongest and deepest mathematical researchers of genuine T-shaped activity.

As well as language/expertise barriers for mathematicians to work with those from other academic disciplines, or across disciplinary boundaries, there can be huge cultural differences. Mathematicians sometimes refer to those outside their discipline as "non-mathematicians", almost in the same way in which religious communities can refer to non-believers, which can sometimes make the mathematical science research community appear aloof to those outside. This can create a defensive reaction among those communities that would genuinely benefit from interaction with mathematical scientists. There is a large community of potential partners for mathematical science research that who's first reaction can be "I was no good at maths at school". We need not only to demystify mathematical science research, but also to understand and celebrate complementary expertise. We must encourage an attitude of there being a completely porous boundary between mathematics and so-called non-mathematics.

3.2 Timescales and the need for better dialogue

Research in the mathematical sciences intrinsically sits at a deeper methodological level than other closely related STEM disciplines such as Physics, Chemistry, Computer Science and Engineering. Even in areas such as Operational Research and Statistics, which have strong motivations in application, the research culture can be oriented towards general methodology. This is not intended as a criticism, and indeed the culture of thinking in general methodology terms, rather than in terms of specific applied fields, allows powerful new methodological perspectives to be brought to practical industrial and government modelling questions. It can however have unfortunate consequences, as described later, if incentives are not managed appropriately.

This means that, typically, additional preparatory work is required to set up a new industry collaboration with the mathematical sciences, compared to many areas within other disciplines – there is less likely to be an existing common language, the industry partner may not be familiar with the area of mathematics or with mathematical sciences ways of thinking, and the mathematical scientists may not be familiar with the application area nor the kinds of timescales and commercial imperative associated with the application.

The evidence in the Bond Review makes it clear that, due to the serious practically relevant skills which exist in the mathematical sciences, there are major wins to be had given appropriate mechanisms. This suggests that KE activities (within universities, within activities such as study groups, and at national institutes such as INI and ICMS) should have this in mind, with sample narratives of how initial contacts with mathematics can lead to full scale projects, and how business development support can help at different stages of project and relationship development. It is also very important that appropriate structured support for follow-up is in place after relevant workshops or brokering events – it can be the case that without such follow-up, the event almost may as well not have happened, as observed repeatedly by the authors of this piece.

There are many schemes out there, like the KTP schemes that mathematicians are not engaging with because of the lack of this contact management and appropriate brokering of expertise. There may also be a lack of recognition in the mathematical sciences community of how wide a range of mathematicians such funding could be relevant to.

3.3 Proposal evaluation and ranking

Our own experience, and that we have heard from others, on the single unified EPSRC Prioritisation Panel for MS suggests that application-orientated research may be at a disadvantage. Such proposals are thoroughly evaluated on all criteria including impact and the interface with other disciplines. The anecdotal evidence is that often some (possibly very minor) criticisms are voiced regarding pathways to impact by reviewers focussed on the application, on top of slight criticism by reviewers focussing on the “novel mathematics”. In contrast, proposals in pure mathematics are essentially not evaluated by reviewers on impact (e.g. often the only tangible non-academic impact is a public lecture, which may indeed be all that is appropriate). On the criterion “research excellence” reviewers tend to be more positive in pure mathematics and mathematical physics, resulting in applied proposals typically being ranked beyond the funding cut-off.

Furthermore, reviewer culture seems to vary significantly between pure mathematics and applied mathematics; in the latter domain (especially in operational research and proposals with engineering application), reviewers tend to award generally lower marks and raise more criticism than in pure mathematics. Data seen by us from EPSRC suggest success rates for less application-oriented grants is approximately double that in non-application-oriented grants. This phenomenon needs careful investigation using EPSRC's latest data.

Of course, it is important that fundamental mathematics is also funded, and we are not suggesting that all EPSRC MS-funded research should be at the application-oriented end, and it is true that application-oriented mathematics can be funded by other panels, such as Engineering or ICT. But there is some evidence to suggest there is not a level playing field. Experience on other EPSRC panels, for example Engineering, suggests that the same problem with inflated scores does not occur, perhaps arising from larger budgets meaning that more projects are funded without 'straight 6s', and the panel has a much wider array of subdisciplines. Yet, more mathematically oriented proposals in Engineering panels tends to fall down if there aren't much shorter pathways to impact than is traditional in mathematics.
Also, we do recognise that pure mathematics can generate impact, although typically on a longer timescale; it merely appears that the award process is somewhat skewed. To level the playing field, a possible solution could be to separate applied and pure work in the prioritisation process to enable like-for-like comparisons and a better balance between applied and pure proposals being funded. It may also be productive for Departments and the mathematical community leadership to discuss with Research Council the circumstances under which proposals from the mathematical sciences can access more applied programme including the 'mission programmes'.

Anecdotally, we have heard consistently from EPSRC that they get very few applications which include requests for KE and public engagement funding - their take on this is a perception that asking for more funds (to undertake these activities) would reduce the chances of success. Therefore, there also appears to be a need for UKRI to communicate more emphatically the desire for applicants to request KE funding.

3.4. Interdisciplinary funding schemes.

The nature of mathematical sciences also has implications for applied research funding schemes. Often, to maximise the impact of both explicitly applied disciplines and mathematical sciences, it is necessary to have these different areas working in collaboration. It is important that funding schemes are set up to encourage this. There is a common perception that, particularly in highly competitive programmes, the review process does not handle interdisciplinary proposals well – there is probably some truth in this, although no doubt some of this feeling in the community is from researchers who have had poorly written proposals rejected correctly. Schemes should also be set up so as to encourage and not create barriers to proposals from/including new methodological expertise – e.g. there should be a reasonable path to engagement for disciplines such as mathematics, there should not be an effective requirement to be present at workshops which only researchers with long existing track records are likely to be at, large consortium calls can sometimes favour teams with long track records rather than those with radical new thinking. These calls often come with short timescales which are anathema to most mathematicians.

It might make sense even in short timescale calls for interdisciplinary and business-led research to think about opportunities for longer term engagement with mathematical scientists and to factor this into a parallel funding calls. This could for example lead to different models at Innovate UK, perhaps using existing mathematical sciences infrastructure such as the INI and ICMS to broker the necessary relationships. Another idea mooted, in the LMS response to the Bond review, is that new kinds of KTPs could be offered which allow more staff time buyout. Although KTPs are being advertised as “research income” and an opportunity to “publish high quality journal papers” (according to the description of KTP benefits on Innovate UK’s website [7]), the actual buyout of academics’ time is limited to 10% to be split among all academics involved. For example, if three academics participate in a project on equal terms, the individual buyout is 3.3% and therefore does not have a tangible effect on freeing up workload for research. Moreover, in the mathematical sciences there is a culture of academics being involved hands on in the research in a way which is less typical in (e.g.) engineering.

3.5 Incentive structures within university mathematics departments.
Incentive structures within universities can also provide significant barriers. Historically, mathematical science Departments in the UK have given little credit in career terms for impact outside the world of mathematical science research. We have heard statements such as: “you should stop spreading yourself so thin, and concentrate on a single deep mathematical goal”; or “individual A (with significant KE track record) has a lower H-index than individuals B and C (who don’t have that track record) and so is not ready to be promoted”. This is changing, partly driven by REF, but also partly by a desire by mathematics departments to make the full contribution to society which mathematical sciences can provide. Indeed, even looking to REF, focusing too directly on REF impact can be counterproductive – it is demotivating to staff, and focusing support and resources too exclusively towards case studies detracts from the wider range of applied research and other industry activity which may or may not ultimately lead to REF case studies.

Certainly, there are many applied activities which can bring significant benefits to industry, society or government, that require skills that are rare outside university mathematical sciences. These present a different challenge from traditional purer mathematical research, but that is not to say a lesser challenge. We need to avoid ‘deep’ and ‘difficult’ being used as proxies for important. The question is what institutional support and reward structures are required to make this happen. Similarly, it is important that across different disciplines appropriate incentive and reward structures are in place to motivate assembly of the right interdisciplinary teams and projects.