LMS BOND WORKING GROUP

AN INITIAL RESPONSE

MARCH 2019

CONTEXT

The LMS Bond working group (LMSBWG) was established to articulate a response to the Bond Review (BR) to be used as input to the two Council for Mathematical Sciences (CMS) committees described below. Its considerations as presented here may also be used by the LMS to inform policy or any current activity arising from the community, research councils, etc. that is triggered by or relevant to the Review. The group has wide ranging experience. It invited suggestions and views from both LMS members and the LMS Council and the resulting input forms an important component of this document.

There are many current initiatives of substantial scale emerging from the community, the funding councils, as well as from the CMS Societies, in response to the Review. These make the work of the LMSBWG timely and demanded that it provide a considered short-term response.

It is noted that the BR has been received enthusiastically across the community for its articulation and vision of "*The era of mathematics*". The additional value to the UK of substantially increased and effectively placed resource for the mathematical sciences is very widely recognised. It is noted that such an assignment needs governance structures that ensure a step change in the interaction between mathematics, mathematicians, and those who can create value out of mathematical imagination and creativity. Extrapolating from current contributions, the increase in value should be huge and the investment would represent a very good use of resource.

The Learned Societies are unified in the shared goal of making this transformative investment in the mathematical sciences a proportionate and sustainable success. The CMS is putting in place a 'two committee model': one, the `strategic committee', chaired by Dr Claire Craig and with a membership that is well known and respected at a high political level, will aim to prepare government for any 'big ask'; while the other, the `academic committee', chaired by Sir Bernard Silverman and with a membership of mathematicians including both academics and those with real world experience, will have the task of working through the recommendations to flesh out the detail of the actions needed.

As argued in the BR, effective knowledge exchange (KE) with the mathematical sciences (and scientists) is not about carrying books from the mathematics libraries and placing them at the feet of potential beneficiaries. The BR makes the case through numerous compelling narrative examples that the core elements in the transition from abstract mathematical understanding to impact are human interactions and endeavours. It is about creating and nurturing effective and imaginative people with strong mathematical skills; getting decision makers to understand the value that mathematical insight can bring to their organisation; and, through

pipelines and flows of people, finding ways to join the two communities together to achieve successful outcomes. There are stunning examples of the impact made by individuals who have initiated entire new directions, and there are also the hugely important steady contributions of mathematical scientists engaged with industry on more predetermined shared projects. The recommendations of the Bond review aim to set out the resources and mechanisms that need to be in place, while the business case substantially addresses the challenge of a step change in impact.

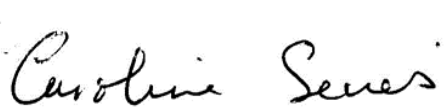
We quote from Lord Stern's preface to the BR: *"New mathematical understanding does not come out of the ether. It requires investment in the pure mathematics that underlies all the rest, in the applications working with partners and other disciplines, in the people, particularly the young who will take it forward, and in understanding of mathematics from the top CEOs and ministers to those in the more technical areas who will do the 'hard graft.'"*

We emphasise in particular the necessity for a balanced portfolio and a continuing investment in the underlying pure mathematics, ensuring that this is not overlooked in the drive for short term KE. There is an existing continuum of research and of people (from the abstract to applications) and a strong evidence base that this continuum already delivers a big return. This existing and successful functionality must be maintained if the drive to an even more ambitious level of KE is to be achieved. Somewhat beyond the scope of the BR itself, KE emerges as part of a larger picture dependent on the health and coherence of the mathematics and mathematics education in the UK. It is crucial to nurture the young people who will be taking KE forward, and to ensure that those who teach them are adequately motivated, supported and resourced. This applies not only to those talented individuals already at graduate level, but essentially in all stages of development from primary school onwards. The UK economy depends substantially on the flow of mathematically imaginative individuals out to deliver value for the wider community.

The challenges of engaging with the initiative of the BR to deliver a strong and sustainable mathematical community which is enabled to achieve ground changing engagement for the UK need to be a primary focus for the LMS and the other CMS societies. It will need creativity in positioning resource, a passion for mathematical sciences in all their diversity, and a clear determination to manage and nurture the full spectrum starting from appreciation of the abstract beauty and clarity of mathematics, though all stages of development, to the implementation of substantial and practical real-world outcomes.

A list of some possible first actions and a list of the membership of the LMSWG are to be found at the end of the report.

Terry Lyons FRS, LMSBWG Chair



Caroline Series FRS, LMS President

OBSERVATIONS AND PRIORITIES

The recommendations of the Bond Review have the broad support of the LMSBWG. They are discussed below together with various suggestions for implementation, under the five headings mapped out in the Review.

We would emphasise that although we strongly support Knowledge Exchange (KE), we do not suggest either that all mathematicians should be directly engaged in KE, or that expansion is possible without extra resource. The evidence of the huge contribution made by mathematical research to the UK is well documented in the review and elsewhere; the contribution is spread across the community and relies for its vitality on a wide spectrum of people and activity. The further development of the KE pathway needs to be recognized and rewarded just as fine research and teaching are; the level and quality of KE should be increased considerably. Mechanisms also need to be developed to recognize the value of the development and application of pre-existing mathematics in new areas. Set against this, it is interesting to note that in the 2014 REF, the highest impact scores were strongly correlated with the highest research scores.

One challenge that the community will need to manage is that doubling or tripling the funding for mathematical sciences, while bringing great benefits, will also reshape the research landscape. This will need careful management to ensure full engagement from those who can contribute. Initiatives need to be approached with care to ensure that they are implemented without detriment to or diminishment of other vital activities. It is important to understand that the pipeline to large scale societal contributions is widely spread and draws broadly from across the mathematical sciences. A critical consideration is that any increase in activity as regards knowledge exchange must not be allowed to impinge negatively either on the teaching and administrative activities which are critical to sustaining the community and producing the next generation of mathematicians, or on the foundational and exploratory aspects of mathematical research which have so often turned out to be fundamental in new applications. It is also important to recognise that high level and creative engagement with practical problems has frequently been shown to enrich abstract mathematical thought and indeed lead to whole new and important areas of abstract research.

1. *Governance*

   i. It is important to stress that KE for mathematics will only work if governance allows for fundamental research, creativity, and risk taking. It needs to allow those involved in KE to additionally engage in high-quality mathematics not directly applicable to the industrial problem. This raises the question of how to free up the time to enable people to do KE work and ensure there is strong interaction with the wider research community. For university staff there are various approaches including buying out of certain jobs e.g. exams and admin or possibly teaching. Experience suggests that the provision of PA, Project manager time or PDRAs who are not tied to a particular

project, or the provision of industrial facilitators, can also be extremely valuable.

ii. It is crucial to recognise, as mentioned above, the absolutely fundamental role played by the teaching of mathematics at both the undergraduate and graduate level, if for no other reason that without it, the pipeline of qualified individuals would rapidly dry up. Any proposed buy-outs of teaching or admin time need to be considered in this context and it is absolutely essential to ensure that fully adequate resourcing is put in place to allow a full complement of academics and support staff to continue with these basic and fundamental roles.

iii. A mechanism is needed to enable setting up a network exchange that would provide a place for people to get together with stakeholders from companies that goes beyond the level of the defined EPSRC maths 'blobs'.

iv. The recently re-named Newton Gateway (formerly Turing Gateway) in Cambridge has already achieved much through setting up relationships between companies and researchers and by encouraging an exchange of questions and ideas. The importance of relationships and their facilitation needs to be emphasised and more widely promoted. More needs to be done to create spaces in which people can act freely, linking different types of companies and mathematicians, thereby releasing far more intellectual value. Shared challenges can be a very effective way to bring disciplines together.

v. It was noted that the effectiveness and success of the Newton Gateway has depended to a very large degree on the excellent and highly skilled staff with their constant efforts to make and maintain contacts between appropriate groups of people. If this or a similar structure is to be replicated, as we would strongly recommend, then having such staff in place will be an essential component of success. The KTN could also play a part if it had the staff capacity and set key performance indicators (KPI) that motivated the seeding of relationships between academic mathematicians and industry on a significant scale.

vi. There are different models for KE. Attention should be paid to their role and scale. It seems likely that there will be a diversity. The Heilbronn model is set up so that individuals undertake KE work for 50% of their time. None of these individuals seem to have any difficulty in subsequently securing jobs in academia, which implies the model of splitting their time seems to work. The reasons for this are twofold: a) the quality of the individuals themselves and b) the value which the non-academic half of their work adds to their academic endeavours. All of these considerations would apply to KE in general.

vii. It is important to bear in mind the nature of the sponsor and how much funding they have available. The Heilbronn situation is unusual in that it has one sponsor with very deep pockets. Other sponsors might be SMEs with an uncertain cash and life

expectancy, and very limited funding. At the opposite end of the spectrum, big companies in the pharmaceutical sector are motivated by the increasing need for AI expertise. Then there are intermediate sized companies, drug discovery start-ups with hundreds of millions of initial investment and a focus on technical solutions. Thus, given the fluid model for business R&D in the UK, it is likely that a variety of approaches will be needed.

viii. Mathematics does not always do well in attributing adequate resources for KE engagement. The Heilbronn model would be to pay 100% of salaries including all costs, obtaining 50% of the individual's time as a direct return. Such a model is not sustainable for small start-ups. Collaborations need to add significant value for both sides to be sustainable. Although both sides will need to support the needs for value from a collaboration, they do not need to share the same overarching objectives.

ix. Any model for a national centre for impactful mathematics would need to be able to distribute resource geographically. This requires attention to be paid in dealing with concerns from those not in close proximity to a centre. From the experience of some members of the LMSBWG, departmental Knowledge Transfer Facilitators (KTFs) can play a crucial role in engaging with local academics from other disciplines and relevant companies. On the other hand, there are equally experiences in which departmental or other official university efforts have been unhelpful. It is therefore important to build on positive experience to ensure that the right mechanisms and people are in place, and that funding should be provided to support such local structures as appropriate.

x. Responding to the LMS consultation very shortly before his death, Sir Michael Atiyah wrote:

> *"I strongly endorse the proposal to create an Academy of Mathematical Sciences. It is essential to have such a body to argue the case for the broad mathematical community. The LMS should throw its weight behind this venture."*

Notwithstanding this strong endorsement, however, the group feels that the development of a possible Academy needs careful and long-term thought, whereas the need to argue the case for mathematics and build the interactions with the community to achieve ground breaking KE is immediate. At a slightly later stage, there will need to be a detailed discussion about the proposal for an Academy, exploring the critical roles envisaged for such a body and how best to achieve them. Funding and the experience from the more basic initial stages of developing KE may be key.

xi. The CMS currently has limited visibility and is not widely recognised as a significant voice for mathematics, even though this was one of the purposes for which it was established. This was picked up in the BR. As one possible remedy for this, the LMSBWG was supportive of the vision that the CMS might work to create a well-

funded and professional communications unit which could promote mathematics and its uses both to mathematical scientists and potential users, and to wider society. This would of course require fund-raising on a considerable scale, but it was believed that there could potentially be a number of wealthy supporters who might be interested in this project. Such a communications unit could indeed be seen as fundamental to the core mission of boosting KE, which would be considerably facilitated if potential partners and mathematicians could better visualise the importance of mathematics and the ways in which these interactions with KE can and do happen. The CMS Societies might wish to consider developing this idea and raising funds explicitly for such a project now.

xii. It is noted that an initial step towards the creation of the Academy of Engineering was to create a Fellowship of active and distinguished engineers who were concerned about the shortage of young people looking towards engineering as a possible career. We wonder whether this model might be a useful one for consideration.

xiii. *In conclusion:* The questions around governance are still at an early stage, and the challenge of ramping up the scale of KE is more immediate. Only after this has happened will it be clear where the priorities lie. It is important to understand the level of activity internationally. Other countries understand the value of KE in relation to mathematics and it will be to the detriment of the UK if we are complacent. (Two members of the LMSBG are independently involved in a current bid for an AI research grant in Hong Kong which has a strong mathematical component. The amount requested was around £45m for a 5 year project.) The Academy will take more time to work out and should proceed more slowly to get it right.

2 *Skills:*

i. The pipeline to achieving Knowledge Exchange is a complex one. Individual contributions can be huge and are not well identified by REF impact; for example, the case of Eric Lander[1] (DPhil maths (Oxford) with a book in Representation theory[2]) became the first author on the human genome project. Equally there is a broad role to be played by students who develop core skills in an area and then go on to exploit those skills in industry. The LMSBWG strongly support a very substantial increase in funding for PhD students. The increase in the training of graduate students will have the biggest impact if it supports a broad portfolio of mathematics and puts in place mechanisms to entice successful students to transition. The LMSBWG endorsed the

[1] Eric Steven Lander, a mathematician and geneticist, is a Professor of Biology at the Massachusetts Institute of Technology, former member of the Whitehead Institute, and founding director of the Broad Institute of MIT and Harvard.

[2] Lander, E.S., 1983. *Symmetric designs: an algebraic approach* (Vol. 74). Cambridge University Press.

importance of computing skills at a high level for all these postgraduate students so that they can easily transition to a wide range of opportunities; however, it felt though that strong fluency in this skill set should be developed at the undergraduate level and a requirement at graduate level. Wanting to have impact at the end of the first degree is worthy and a useful entry point for some and should be supported but is unlikely to generate the very big fish and should not be the only direction of this support. The involvement of undergraduates and the creation of culture is important: Cambridge has summer research projects in which undergraduates are working on 8-10 week industrial problems (mostly linked to a supervisor in the department) that change attitudes and build collaborations. The value in a larger throughput at all levels seems clear.

ii. It should be recognised that new applications are constantly emerging from areas of pure mathematics. The talents required for fundamental mathematical research and those for successfully engaging with applications are different, and one needs a pipeline that supports all types of activity with a steady flow out to other roles. Thus what is needed are additional resources, indeed the current limited resource is already achieving enormous results, and is well allocated.

iii. It is important to ensure that the mathematics syllabi taught at undergraduate level are designed to include sufficient in-depth material which keeps up, informs and inspires with modern developments. At a time of rapid development in some areas, this is not always easy or well done.

iv. There was full agreement that bringing people together works successfully, and can help facilitate relationships and increase visibility. It is important to bring the right people together and support and build long term collaborations. Effectiveness and sustainability are best achieved if the industrial partners understand how the engagement can add organisational value and have the authority in their organisation to drive the collaboration forward and achieve their goals. Thus, establishing contacts at the right level of a given organisation is crucial. The mathematical scientists need to understand how the collaboration will bring value to them. This program should not be restricted to just one site. These arrangements require a diversified model. Done on a scale, such engagement would quickly raise visibility and increase the focus on the mathematical sciences.

v. The people pipeline is arguably the most important part of the KE pathway, and we strongly endorse the recommendation for a substantial additional flow of at least 100 more mathematics PhD students a year. The proposal that CDTs could with benefit embrace a broad spectrum of mathematical science, from foundational to applied, resonated strongly: creating a positive and fluid environment for knowledge exchange at the doctoral level is desirable across the spectrum of mathematics. It is also important that mathematical scientists come to appreciate the skill sets of their colleagues. Moreover, in a context of substantial increase in numbers of doctoral students, it is likely and desirable that many will proceed to cutting edge non-

academic positions of influence. It is important that such individuals have the broader skills needed to excel in those roles. The average time for these PhDs, particularly in interdisciplinary projects where it is essential that students gain a detailed facility in least one discipline in addition to a broad basic training, should be four years.

vi. Geographic diversity is important and a scalable model should facilitate collaborative engagement across the entire research active UK faculty in the Mathematical Sciences. A substantial fraction of the studentships should be awarded using criteria that encourage diversity and engagement across the whole university system and also with SMEs etc., to build a truly national KE engagement. Equally, a significant proportion of the studentships should be based on excellence with the intention of nurturing the huge contributions made by some of the most mathematically talented individuals.

vii. One way for students to experience real engagement with value creation is to build in an industrial placement. Organising these is challenging, as they work most effectively if there is a clear connection with the student's research. Ensuring high level computing skills facilitates opportunities for successful placements.

viii. The direct business case for a model along the lines of the Study Groups with Industry is felt to be weak, but as a training resource for students, it is very good. Getting adequate flow of resource back from KE is as important to the researcher in the academic institution as to the business.

ix. Professional mathematicians are experts, even senior figures; they have many opportunities to communicate with students, other departments, industry, government, potential collaborators, and the public. It is important that they are broadly aware of and confident to communicate, in a way that transcends their subspecialty, the essential roles played by the mathematical sciences in society today.

x. It is important to enable undergraduates to understand and appreciate that what they learn re-emerges and reconnects to the wider world at a later stage. A national centre aimed at communication of mathematics could help. Summer research projects for undergraduates would also help.

xi. Mathematical Sciences teaching is a vital part of the pipeline and its quality and diversity must not be sacrificed for short term KE. Significant concerns were raised about buy outs and their unintended consequences. We repeat that any funding or resource going towards KE must be additional and not at the expense of already hard-pressed and vital teaching and other research staff. We also draw attention to the opportunity for KE that emerges from service teaching. Ideally, mathematicians should always be involved wholeheartedly in service-teaching as it provides an important way to encourage engagement in the university setting between mathematical scientists of all backgrounds and other mathematics consuming disciplines, in addition providing additional resource.

xii. One should be clear that not everyone will be able to do everything all of the time. A depressing story that one often hears is "I find myself feeling constantly guilty for not generating impact, so I take on too much admin to compensate, and then my research and teaching suffers, and I feel stressed and miserable." Everyone needs to be equipped with the training and opportunities to play to their strengths - which may change during their careers - recognising that our strength is in diversity. The danger of being judged by REF, TEF and now KEF is that everyone feels the pressure to do everything.

Points raised in relation to specific recommendations:

Recommendation 8:

- We support this recommendation (which is indeed already implemented in many if not most mathematics courses). We suggest that it should also be a requirement for incoming PHD students to acquire, if they do not already have, competence in a serious programming language to for example the standard required by banks for quants.

Recommendation 9:

- The Royal Society have an excellent model of Industry Fellowships for academic scientists who want to work on a collaborative project with industry and for scientists in industry who want to work on a collaborative project with an academic organisation. This could perhaps be expanded and specifically encouraged for the mathematical sciences.

- It is important to have better structures in place to enable people to return to academia after a period in industry. Currently this is very difficult.

- In Holland it is common practice in many lectureships for the individual to be required to go out to industry. Although in some cases this may have been successful, there are also clear examples where the practice has proved counterproductive.

Recommendation 12:

- Unintended consequences for career progression need to be thought through, see above comments on the importance of teaching and university admin.

- Should KE be seen as contributing to academic life on a par with research, teaching and administration?

- Faculty resource must be increased with the student intake.

3 *Resources and infrastructure*

i. While the Heilbronn model has a lot to recommend it, there is just one funder with significant funds. It would be necessary to identify exemplar relationships with other partners to replicate this. Fields such as medicine have succeeded to a good extent.

ii. There are many organisations competing for the advice of the Alan Turing Institute (ATI). One learns from the explosion in data science that it is important not to seek relationships with everyone, but focus only on those that are key, with proper problems, core to their organisations, that need solving. Identifying sustainable

exemplar relationships is essential. Alumni of collaborations should be nurtured and can help initiate new ones.

iii. An additional challenge is to reach areas of business, government, medicine and others in which there is currently no realisation that mathematics has a role to play in their activities. It is not safe to assume that the potential role of mathematics will be immediately recognised and valued.

iv. There is a challenge with timescales in different industries and different disciplines. For example, engineers may come up with controlled solutions focussed on problems as articulated, whereas mathematicians might be slower with ideas, but show radical mathematical imagination in generalising more far-reaching solutions. Expectations need to be managed, and interdisciplinary team approaches considered.

4 *Regional*

i. Regional diversity is essential but difficult to manage. The community needs to articulate a clear business case for this (drawing from Bond, around opportunity, the needs of business regionally) and should look to give pointers on how this can be supported through appropriate funding streams and structures which might reward relationships, interactions and support of regional industry rather than being based solely on research excellence.

ii. Recommendation 19 suggests dedicated teams in university mathematics departments acting as KE facilitators. The key is to hire good people on an appropriate scale. The experience with the Turing Gateway has been that the role of a (non-mathematical) event organiser was absolutely the key to its success. Funding is needed to initiate the process.

5 *Government*

i. There was full agreement that the Government Chief Scientific Advisor Patrick Vallance should, in collaboration with government and other relevant bodies, review access to, use of, and impact achieved by, the mathematical sciences. This would increase visibility and impact.

ii. As a matter of priority, the mathematical sciences should be encompassed in the HMRC definition of science and technology and therefore in the tax-credit scheme. It was agreed that the CMS Strategic Committee should lobby for this to be rectified and we suggest that this should be written into the remit of this Committee. This proposal should be made to the CMS. In addition, the CSA should be approached and asked how to bring this about. [It is understood that moves are already being made on this issue.]

iii. It was suggested that it might be more appropriate for the Strategic Committee to look into the other Government proposals in the review.

Ethics

The issue of ethics in mathematics has been raised in relation to the Review. This issue goes beyond KE although there will be plenty of examples generated by KE. Mathematics is probably behind the curve. The ATI has an Ethics Helpline and a data-ethics group; if research involves people, then ethics approval is generally required. Mathematics may well be used to make decisions that people do not consent to about their lives. The issues are serious and need better attention.

Engineering departments have ethics faculty, so do medical departments, and courses are it is being introduced in some computer science courses around maths and the misuse of stats (although these seem mild examples today).

What can mathematical science community do? This is a live issue in many quarters. There may be scope for organizing events on ethics for mathematicians. Possible inclusions could be mathematics in the law, in forensics etc., in detecting money laundering and closing bank accounts, in data mining and detection of fraud, climate change and the ethics of the way we do our work (travel, computing energy). It is noted that a conference on Ethics in mathematics is to be held in Cambridge in April 3-5, see:
https://ethics.maths.cam.ac.uk/EiM2/

APPENDIX: SUGGESTED POSSIBLE FIRST ACTIONS.

1. Increase number of maths PhD students
2. Review the provision of computing skills, their currency, and their standard, in undergraduate mathematical training. Do they reflect the increased skill sets of incoming students?
3. One or more new centres for Knowledge Transfer along the lines of the Newton Gateway; these could be either self-standing organisations or satellites of the NG. This should take account of place: possibly tie into the Northern Powerhouse.
4. The KTN should increase its mathematical provision and combine it with a measurable challenge to establish new collaborations between academic mathematicians and industry. There should be a requirement by UKRI/Innovate UK that programmes in the Strategic Priorities Fund actively include mathematicians in their teams; evidence that the value of mathematical involvement in these large projects (e.g. the battery initiative) is not adequately appreciated by investigators and the opportunity cost in their omission is likely substantial and not accounted for. The KTN could help identify the mathematical science collaborators. Success in this area could dramatically increase the level of KE in ways that address the need for funding to follow engagement.
5. Facilitation of short-term placements or secondments for academics in industry or other partners, including possibly in other university departments. This could be at the graduate, postdoc or more senior level. Such a placement would not necessarily be in a subject in which the individual was doing research, and there would not be a presumption that the individual would necessarily continue in this direction at the end of the placements, although of course one would hope for experience and enrichment in both directions to have taken place.
6. Refresh Deloitte report.

Membership of the LMSBWG

Terry Lyons (Chair; Oxford); Carola Bibiane-Schonlieb (Cambridge); Peter Cameron (St Andrews); Francis Clark (Swansea); Mike Giles (Oxford); John Greenlees (Warwick); Nick Higham (Manchester); Peter Landrock (Cryptomathic); Miranda Mowbray (Bristol Computer Science); John Toland (Bath).

In attendance: Caroline Series (LMS President), Jon Keating (LMS President Designate).