A Knowledge Exchange Connected Centres Network for Mathematical Sciences

A Consultation Document

December 2021

Foreword

This document builds on a vision put forward by Professor David Abrahams, then Director of the Isaac Newton Institute (INI), and Jane Leeks, Manager of the Newton Gateway to Mathematics, in response to recommendation IV of the 2018 'Era of Mathematics' Bond Review of Knowledge Exchange (KE) in the Mathematical Sciences to create a "*national centre in impactful mathematics... [to] act as a national KE hub"*.

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They developed a proposition to create a step change in the scale, connectivity, and coordination of mathematical sciences KE infrastructure in the UK. Subsequently, INI was successful in securing seed funding (as part of the EPSRC Additional Funding Programme for Mathematical Sciences) to initiate this bold vision.

INI recognised the need for a Connected Centres Network (CCN) to be an entity owned by the whole mathematical sciences community; therefore, it was necessary for it to be developed independently of the Newton Institute, even though INI will hope to provide underpinning financial and administrative support in its early years. Thus, in June 2021, INI asked both of us to develop the idea into a practical implementation plan which could deliver this proposition, whilst being sensitive to the needs of researchers, practitioners, potential end-users, and KE professionals[1]. What is offered here is an ambitious model for consideration by the community; it is a consultation paper.

An important aspect of this consultation paper is that it has been developed alongside a Green Paper for a new National Academy for the Mathematical Sciences. A successful CCN could,

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[1] Throughout this document we are careful to identify distinct stakeholder groups by this nomenclature: researchers refer to mathematical scientists or others working in academia, KE professionals are those whose primary responsibility is fostering relations and activity between those inside and outside academia. Practitioners and end-users are those working in industry, business, commerce, government, charitable sector, NGOs etc., who respectively are mathematical scientists or require the services of mathematical scientists. In what follows, we ask that any mention of industry, or of business, be interpreted in this very broad sense.

in time, provide a critical element to such an Academy, connecting academic and broad practitioner and end-user communities in a coherent and substantial way.

We are very grateful to the many researchers, industrialists, and policy experts, who have generously given their time to contribute to this document through insightful discussions.

We seek your input to all aspects of the CCN, but ask specifically that you consider the following questions.

- Which aspects of the proposal appeal to you most?
- Are there any activities missing?
- Which activities should be prioritised, and why?
- Are you content with the CCN structure and are there ways to make it more inclusive?
- For business, industry, and government: are the mechanisms for engagement appropriate, and end-to-end?

We seek your input on these questions by 21st January 2022. Please complete the following short form: https://tinyurl.com/CCN-KE-Response

Should you have any specific queries please email connected.centres@newton.ac.uk

Dr Joanna Jordan (RTTP), Dr Matt Butchers (KTN)

Preface

On behalf of the Isaac Newton Institute, I am most grateful to Jo and Matt for their extremely hard work in taking a broad, and perhaps rather nebulous, vison for an enhanced KE resource for the UK, and, via expert knowledge and broad consultation, turned this into a detailed and concrete proposal for a Connected Centres Network for the Mathematical Sciences. Many thanks are also due to the many experienced researchers, end-users, KE experts, and other stakeholders, who have given their feedback on earlier versions of this consultation document. I believe what is presented is a bold and inclusive vision for the way that we can 'join-up' the many KE activities going on around the country, and add coordination, resource and expertise, to create something new and highly innovative. I hope you will read this document with interest and we look forward to receiving your feedback.

Professor David Abrahams (Cambridge) – December 2021

The Knowledge Exchange Connected Centres Network for Mathematical Sciences will:

- Massively scale up KE activity in the UK, leveraging the experience of the **mathematical science national infrastructure**

- draw together **researchers, practitioners, end-users and professionals** into Forums which interface with the various activities

- **Supporting existing activity** in the community whilst growing the network by nurturing **untapped pool of researchers, practitioners, and end-users**

- deliver activities through **linked projects overseen by a central team**

- **coordinate support for mathematical science KE projects** from beginning to end

draw together a national calendar of events

trial innovative methods for one-to-many brokerage and translation

strengthen the mechanisms for practitioners and end-users

coordinate a national programme of internships

develop a representative network across all UK mathematical sciences departments

raise awareness of Innovate UKs KTP programme

provide additional support for the delivery of smaller Study Groups

raise awareness of the value of mathematical science iCASE studentships

provide enhanced support for the UK European Study Groups with Industry

support and grow interdisciplinary collaborations with mathematical scientists

develop professional mathematical science KE training

enable a national community of KE fellows

learn from and develop technical mathematical skills courses

enable a national, pooled, critical mass of specialist mathematical sciences KE professional staff

raise awareness of commercialisation programmes

promote and/or run transferable skills training courses

make modelling weeks more widely available

Practitioner and End-user Forum

Creating a voice for practitioners and end-users

Brokering connections

Creating mobility

Multi-institution central body

Creating capacity

Low-risk, high reward entry points

KE Champion Congress

Developing skills

KE Professional Forum

Executive summary

1.   The mathematical sciences constitute a discipline that has vast utility beyond developing fundamental science. In the words of Lord Nicholas Stern[2] *"its influence permeates economic and social activity and its influence and impact are profound"*.

2.   The relationship between the different parts of the discipline, practitioners, other disciplines, potential users, and professionals is delivered through knowledge exchange (KE) activities.

3.   We use Professor Philip Bond's definition of mathematical sciences KE as "*[seeking] to actively engage with other research fields, industry and government. It aims to understand and be concerned with the end use of mathematics. It seeks to understand potential uses of mathematics so that superior tools, techniques and algorithms may be developed for them. This often requires the creation of new mathematics. Through translation KE takes 'the books off the shelf' and uses them to solve real-world problems. Real- world applications have always provided challenges which can only be solved by creating new or sharper mathematical tools. These new tools are then available for use on other problems. **In brief, the goal of KE is to maximise the impact of the mathematical sciences.**"*[2]

4.   The UK excels in many aspects of KE, but, as has been the subject of many reports, it can do better. There is an untapped pool of researchers, practitioners, and end-users who, with some enhanced support, could make a big difference in maximising the impact of the mathematical sciences.

5.   This document sets out a proposal which seeks to create a Connected Centres Network (CCN) which **massively scales up KE activity in the UK, fostering the experience of the mathematical sciences national infrastructure and is inclusive of researchers, practitioners, end-users, and professionals. Activity will be delivered through linked projects overseen by a central team. These**
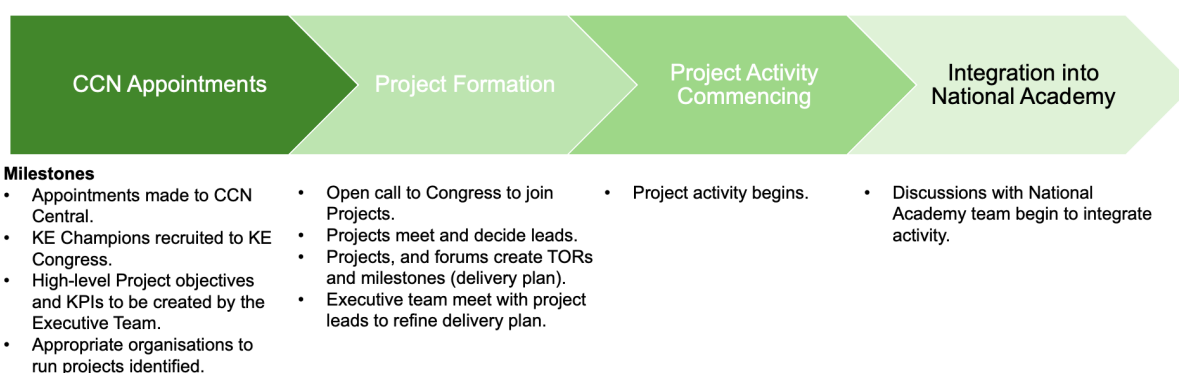
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[2] https://epsrc.ukri.org/research/ourportfolio/themes/mathematics/strategy/kereview/

projects will support, but not subsume, existing activity in the community, providing end-to-end support for mathematical sciences KE.

6. To realise this enhanced impact, the CCN will deliver the following outcomes:

- **strengthen the mechanisms for practitioners and end-users** to a) access the breadth of mathematical sciences needed to support their work and b) enhance their ability to engage in pre-competitive mathematical sciences challenges;
- **coordinate a national programme of internships** that is open to PhD students and Early Career Researchers (ECRs) from any Higher Education Institute (HEI);
- **raise awareness of Innovate UK's KTP programme** amongst both the academic, practitioner, and end-user communities;
- raise awareness amongst practitioners and end-users, in particular iCASE holders, of the **value of iCASE studentships**;
- develop a national programme which will enable staff time to be bought out and help encourage, **support, and grow interdisciplinary collaborations with mathematical scientists;**
- **enable a national community of KE fellows;**
- **enable a national, pooled, critical mass of specialist mathematical sciences KE professional staff** whose expertise could be accessed by any department;
- **make modelling weeks more widely available** to ensure best-practice training in 'real-world' problem formulation and solution;
- **promote and/or run transferable skills training courses** (including talking with industry, how to give presentations, how to communicate effectively, etc.) in order to be credible when working with companies;
- raise greater awareness of existing (or initiate new) **commercialisation programmes;**
- **learn from** the successes of existing **training schemes** for practitioners and (potential) end-users **in technical mathematical sciences skills and develop bespoke courses**;
- **develop professional mathematical sciences KE training**, both for dedicated KE staff and academics with KE leadership responsibilities;
- offer additional structure to **provide enhanced support for the UK European Study Groups with Industry (ESGI) experience**, increasing the likelihood of long-term collaborations;
- **provide additional support for the delivery of smaller Study Group** sessions along with the UK ESGI;

- **develop a representative network across all UK mathematical sciences departments** to quickly identify the 'best' people to signpost KE opportunities to;
- **trial innovative methods for one-to-many brokerage and translation;**
- **draw together a national calendar of events.**

7. The CCN can achieve its objectives by delivering a number of linked projects which group and enable the various outcomes above. These projects will be delivered under the direction of a CCN Central Team, and within it an Executive Team, which draws together the knowledge and experience of the mathematical sciences infrastructure.

8. Fundamental to the success of the CCN will be the creation of forums which convene stakeholders; researchers, practitioners, professionals, and end-users who will populate the project teams. KE Champions from every UK mathematical sciences department will be encouraged, forming the KE Champion Congress.

9. These projects will be run by and for the various stakeholders, with oversight and coordination from the CCN Central. However, the delivery and operation of each project will be delegated to organisations already established and suited to delivering such activities; most likely parts of the existing mathematical sciences national infrastructure.

10. A high-level diagram for how the CCN might begin to form, and some of the essential early milestones, is shown below:

CCN Appointments	Project Formation	Project Activity Commencing	Integration into National Academy
Milestones			
• Appointments made to CCN Central.	• Open call to Congress to join Projects.	• Project activity begins.	• Discussions with National Academy team begin to integrate activity.
• KE Champions recruited to KE Congress.	• Projects meet and decide leads.		
• High-level Project objectives and KPIs to be created by the Executive Team.	• Projects, and forums create TORs and milestones (delivery plan).		
• Appropriate organisations to run projects identified.	• Executive team meet with project leads to refine delivery plan.		

11. CCN progress will be monitored against milestones and KPIs which will be defined by the Project Leads and regularly evaluated by the Chair of the Executive Team. The Executive Team will monitor the progress of the developing National Academy to ensure that at the right time, the CCN will integrate with it.

Chapter 1: Background

The Era of Mathematics - KE Connected Centres

12.   The need for mathematical sciences in industry, society, and other science has never been so important. The 2018 Review of Knowledge Exchange in the Mathematical Sciences, chaired by Professor Philip Bond, articulated the value and imperative for an improved infrastructure to support the translation of mathematical sciences into these various areas[1].

13.   Amongst the nine principal recommendations was number IV which proposed *"a national centre in impactful mathematics for the UK should be created to work with industry and government to drive mathematical research through to commercialisation. This could be based on existing models... [and] act as a national KE hub"*.

14.   This recommendation has led to discussions around a distributed infrastructure to support KE in the mathematical sciences - one that includes and supports mathematical sciences activity no matter the scale, supported by some central function, charged with coordination[3].

15.   In 2020, the Isaac Newton Institute successfully secured funding from ESPRC's Additional Funding Programme for Mathematical Sciences for its various activities, including budgeting for a CCN Manager and Assistant to develop and deliver the concept.

Virtual Forum for Knowledge Exchange in the Mathematical Sciences (V-KEMS)

16.   In parallel to the above activity, the world has had to adapt to a new way of working in the midst of a global pandemic. This paradigm shift has required new technology adoption, and necessitated a more joined-up capability in the mathematical sciences to deliver an effective response to the pandemic.

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[3] https://youtu.be/WU57E0J7Q_o

17.   Amongst the many initiatives established to mitigate the pandemic's impact was the Virtual Forum for Knowledge Exchange in the Mathematical Sciences (V-KEMS)[4] set up in March 2020. This joint venture, between various actors in the mathematical sciences KE infrastructure[5] and key researchers, has proved very effective at developing and delivering activities to address several diverse impacts of the pandemic.

18.   In essence, the proposition for CCN is to create a structure which builds on the existing strengths in KE across the country, learning from the collaborative remote engagement mechanisms from V-KEMS, and expanding it beyond the capacity currently available.

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[4] https://www.vkemsuk.org/

[5] Joint venture between INI (including its KE arm, the Newton Gateway to Mathematics), the International Centre for Mathematical Sciences (ICMS), and the Knowledge Transfer Network (KTN).

Chapter 2: The proposition

This list of high-level objectives summarises the aims of the CCN.

- **Massively scale up a national KE network which fosters activity across all mathematical sciences departments in the UK, irrespective of their size, location, or experience.** KE can be seen as the activity of those research departments that are fortunate enough to be able to support it. This initiative democratises KE by supporting research groups in their KE endeavours no matter their experience or capacity by providing leadership, and sharing of experience, across the network.

- **Create a diverse and inclusive community of researchers, practitioners, potential end-users, and KE professionals.**[6] Barriers to KE include cost, time, and language/translation difficulties between different groups and communities, amongst others. This initiative will work with all parties to reduce these barriers and support interdisciplinarity.

- **Strengthen the interaction between researchers, practitioners, and potential end-users**. Creating a voice for practitioners and end-users in a flexible manner to reflect the ever-changing needs from industry, whether regional, sectoral, or technical.

- **Coordinate and resource activities from the mathematical sciences infrastructure which support KE efforts at the departmental, regional, and national scale. Balancing this support without undermining or destabilising existing local or regional relationships.** There are many KE initiatives in the UK that the community can learn from, the aim being to add value to these by sharing best practice, learning from how other organisations do successful KE, and democratising that learning across the UK, without interfering in individual relationships.

- **Proactively seek to engage more potential end-users and practitioners into the network.** The barriers to new entrants should be reduced, particularly SMEs, and the route to entry should not be driven by what level you are in your organisation, the size of your organisation, or where you are geographically.

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[6] The reader is referred to footnote 1 for definitions of these terms, recalling that practitioners are identified as mathematical scientists outside of universities (in business, industry, government, etc.), who would benefit from engagement in KE activities with academic researchers.

Campaigns to bring people into the KE activities across the UK will be undertaken.

- **To seed the initiative, INI will look to support a full-time CCN Manager and Assistant, and a part-time academic position (or positions) to help establish relationships, an effective governance structure, and an initial programme of activities.** These roles will act for the national good and drive the activities expanded upon in detail in the following chapters of this document.
- **Ultimately, the CCN activities will interface with the recently proposed National Academy for Mathematical Sciences[7] via the Community Affairs Committee**.

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[7] A National Academy for Mathematical Sciences Green Paper is available at
http://www.cms.ac.uk/wp/national-academy/

Chapter 3: The need for a Connected Centres approach to KE

19.   For this paper, we have reviewed, via consultation, the needs of four primary groups of people[8].

- **Researchers** - those in university departments wishing to engage in mathematical sciences KE[9]. In particular, bridging links across disciplines.

- **Practitioners -** mathematical scientists outside of universities (in business, industry, government etc.) who wish to engage in KE activities.

- **Users and potential end-users -** employees from business, industry, and government, who are not practising mathematical scientists, who wish to engage in mathematical sciences KE.

- **KE professionals** - those employed at universities to facilitate mathematical sciences KE, either mathematical sciences specific roles or those in central Technology Transfer Offices.

Need from researchers

20.   Collaboration with business, industry, and government - which leads to the generation of external income - is typically high on the priority lists of most universities. This is partly driven by successive governments' push for greater emphasis on challenge-led research and manifested via the research funding bodies' impact agendas and the assessment of impact via the Research Excellence Framework (REF)[10].

21.   KE is all about people and building personal relationships. This is a very time-consuming activity, and the skills and entrepreneurial mindset required do not always fall in the skillset of academics. Where it does, there should be greater recognition from researchers' universities on the value of working in KE[11].

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[8] Whilst recognising that some roles incorporate elements from more than one category.
[9] We deliberately do not distinguish between researchers who are, or are not, members of mathematical sciences departments.
[10] Through impact case studies and environment statements.
[11] https://re.ukri.org/knowledge-exchange/knowledge-exchange-framework/

22.   There are a range of sizes of mathematical sciences departments nationally, which have very different levels of experience in KE. For example, in less well-resourced departments:

- visibility can be an initial barrier to making external contacts;
- with only a small number of staff interested in, or working in, KE, i.e., a limited critical mass, resourcing industry meetings and then projects, can be a challenge;
- organising events, and ensuring they run smoothly carries a big overhead;
- the costs of hiring a full-time equivalent (FTE) KE role in smaller mathematical sciences departments is prohibitive; however a share of a specialist might be more achievable.

23.   To ensure a critical mass, and strong people pipeline, of KE proficient researchers, it is important that there is equal and easy access to KE training and opportunities for any interested party at any career stage.

Need from practitioners and potential end-users

24.   Practitioners and end-users surveyed both for this consultation document, and as supporting evidence for the Bond Review, highlight a number of motivations for their engagement in mathematical sciences KE. This is to:

- gain greater insights into their own research, technology, or data;
- gain access to expertise not available internally;
- solve a specific problem;
- help with horizon scanning/ideas exploration;
- gain access to early-career researchers for secondments, studentships, recruitment, etc;
- increase internal capacity via training.

25.   It is a full-time job to oversee what science is emerging from the research base. Quick brokering and signposting is of great value to those practitioners and end-users wanting to access the latest science. This brokerage needs to be done outside of the confines of one university, or one 'sub-discipline' - insight is often at the interface of many areas of the mathematical sciences or other disciplines.

26.   There is a need to train and upskill researchers, practitioners, and end-users in many of the aspects of collaborative working. For example, more widespread knowledge of modelling and problem formulation, commercialisation, IP etc., to support the interaction.

27.   Research and innovation mechanisms are frequently tailored towards long-term research projects. Often a more flexible exchange of ideas is needed, which can make such projects more cost-effective to users.

Need from KE professionals

28.   Mathematical sciences KE is recognised as distinct from KE in other subjects.
   ● Specialist mathematical sciences KE professionals have been shown to add significant value to departments.
   ● There is no defined career path for KE professionals specialising in mathematical science.
   ● Training is typically "on-the-job".
   ● Posts are generally funded by short-term research grants, rather than core staff budgets, which adversely affects both staff retention and continuity of any long-term relationships with external partners.
   ● Specialist mathematical sciences KE or Business Development roles are typically only found in larger departments.
   ● There can be a lack of understanding by central university Business Development or Technology Transfer offices of the mathematical sciences' requirements.

Need from users and potential users

29.   There are vast untapped communities from business, industry, and government, who could benefit from, and enrich, mathematical sciences KE who are yet to engage with the discipline. This 'untapped community' is illustrated starkly in the 2015 Dowling Review of business-university research collaborations[12]; out of the 11,690 collaborative projects reported in 2015, only 2% involved mathematical sciences.

30.   Despite this evidence, the appetite for engagement with the mathematical sciences continues to grow, as evidenced by the many new and interesting organisations taking part in KE events, such as in Study Groups (and Virtual Study Groups)[13,14].

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[12] https://www.raeng.org.uk/publications/reports/the-dowling-review-of-business-university-research
[13] https://www.cambridge.org/engage/miir/public-dashboard
[14] https://www.vkemsuk.org/news

Chapter 4: Added value and aims of the Connected Centres Network

31. The text below details the outcomes that the proposition should aim to achieve. They are built on the analysis which can be found in Annex 2 which assesses the gaps and/or weaknesses in the existing activity for KE in the mathematical sciences in the UK.

Creating a voice for practitioners and end-users

32. The CCN could strengthen the mechanisms for practitioners and end-users to a) access the breadth of mathematical sciences needed to support their work and b) enhance their ability to engage in pre-competitive mathematical sciences challenges.

Creating mobility

33. The CCN could coordinate a national programme that is open to PhD students and ECRs from any HEI. It could help source industrial challenges, and broker academic supervisor expertise if not available in the same HEI as the researcher. An annual internship showcase event could help cement relationships and seed new ones.

34. The CCN could raise awareness of Innovate UK's KTP programme amongst both the academic, practitioner, and end-user communities. Given additional funding, the CCN could support greater academic-time buyout for supervision, when required.

35. The CCN could raise awareness amongst practitioners, end-users, and in particular iCASE holders (often not mathematical scientists) on the value of recruiting mathematical sciences PhD students via iCASE studentships. Additionally, the CCN could collate success stories of completed projects.

36. The CCN could develop a national programme of placements which will enable staff time to be bought out and help encourage, support, and grow interdisciplinary collaborations with mathematical scientists. It would simplify HEIs' participation, and help provide equal access to the mathematical sciences across the country.

Creating capacity

37.   The CCN could enable a national community of KE fellows. A sizeable group provides identity, and greater choice of projects assists matchmaking between fellows and industrial partners. The CCN could provide job security by underwriting KE fellows' contracts for a fixed period, as well as designing a framework for career progression, e.g., senior KE fellows providing mentoring or line management.

38.   The CCN could enable a national, pooled, distributed critical mass of specialist mathematical sciences KE professional staff whose expertise could be accessed by any department. This would allow academic staff to focus on the technical aspects of projects, as well as supporting KE activity in smaller departments. In parallel to the KE fellows, the CCN could design a framework for career progression. This would require access to significant resource, potentially through UKRI. These KE professionals could be based across the country and coordinated by the CCN.

Developing skills

39.   The CCN could make best-practice training in problem-based case studies (such as the University of Bristol's Department of Engineering Mathematics' 'Maths and Data Modelling') and modelling weeks more widely available. It could encourage greater participation in the international (online) mathematical modelling competition for undergraduates, potentially with preparatory training sessions. The CCN could run additional mathematical modelling weeks.

40.   The CCN could promote and/or run transferable skills training courses, such as the Royal Statistical Society (RSS) 'Consulting Skills' course. It could coordinate 'boot camps' as part of a suite of learning activities (including talking with industry, how to give presentations, how to communicate effectively, etc.,) in order to be credible when working with a company.

41.   The CCN could raise greater awareness of existing, well-regarded, programmes such as the Young Entrepreneurs Scheme (YES), open to postgraduate students and ECRs, and SetSquared's Innovation to Commercialisation of University Research (I-CURE), or, given additional funds, develop its own programme.

42.   The CCN could learn from the successes of the Academy for PhD Training in Statistics (APTS), and NATCOR's Operational Research and Business Analytics courses, and expand their reach. Training courses could provide a valuable income

stream for the CCN. They also offer an attractive proposition for new industrial partners to engage with the CCN for the first time, providing a stepping stone for other forms of engagement.

43.   The CCN could develop professional mathematical sciences KE training, both for dedicated KE staff and academics with KE leadership responsibilities. Anecdotally, the mathematical sciences community seems largely unaware of PraxisAuril. In the long term, greater course uptake could lead to more Registered Technology Transfer Professional (RTTP) accreditations - the international professional standard for KE practitioners. The CCN could work with professional societies to provide recognition through prizes for excellence in KE.

Low-risk, high-reward entry points

44.   The CCN could offer a modest amount of additional structure to provide enhanced support for the UK ESGI experience, increasing the likelihood of long-term collaborations. A permanent website, account management, and a standardised process for capturing long-term impact and results of participation, would be valuable resources. A realistic business model, which costed academic and professional staff time would aid sustainability.

45.   The CCN could provide additional support for the delivery of smaller Study Group sessions alongside the UK ESGI. It could coordinate timings, problem allocation, and follow up, as well as diversifying the industrial, participant, and host institution involvement by using these smaller more flexible sessions. It could also create a good-practice handbook/training for running shorter SGs, especially in smaller departments, and provide a small funding pot to allow departments to involve SMEs.

Brokering connections

46.   The CCN could develop a representative network across all UK mathematical sciences departments to quickly identify the 'best' people to signpost KE opportunities.

47.   The CCN could trial innovative methods for one-to-many brokering and translation. For example, extend the recent success with the Analysis for Innovators (A4i) and Innovation Exchange (iX) programmes with KTN and Innovate UK. This could involve providing a 'front door' for practitioners and end users to bring their problems, which

could be formulated into more mathematical questions by a group of experienced representative researchers, and subsequently brokered.

48.   The CCN could draw together a national calendar of events which covers its self-initiated activities and also those led by other researchers, practitioners, KE professionals, and end users.

Chapter 5: Structures to deliver the Connected Centres Network

Relevant organisations and their legal structures

49.   Below we briefly consider some organisations who deliver mathematical sciences KE activities mentioned in Chapter 4. The purpose of this is to review what structures exist that the CCN could learn from and/or deliver its activities through.

Heads of Departments of Mathematical sciences (HoDoMS)

50.   HoDoMS[15] is the representative body for Heads of Departments of Mathematical Sciences in UK Universities and aims to discuss and promote the interests of HE Mathematical Sciences in the UK and to facilitate dialogue between departments. Since 14th August 2018, HoDoMS has been incorporated as a Company Limited by Guarantee.

Knowledge Transfer Network (KTN)

51.   KTN's[16] mission is to connect ideas, people and communities to respond to economic/social challenges and drive positive change through innovation. KTN's diverse connections span business, government, funders, research and the third sector. KTN is a Company Limited by Guarantee, incorporated on the 1st April 2014.

Alan Turing Institute (ATI)

52.   The ATI[17], headquartered in the British Library, London, was created as the national institute for data science in 2015 by five founding universities and EPSRC. In 2017, as a result of a government recommendation, it added artificial intelligence to its remit. Eight new universities joined the Institute in 2018.

53.   Since its inception, the ATI has been funded through grants from Research Councils, university partners, and from strategic and other partnerships. The ATI is a registered

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[15] https://www.hodoms.org.uk/Index.html
[16] https://ktn-uk.org/
[17] https://www.turing.ac.uk/

charity in England and Wales and a Company Limited by Guarantee incorporated on 26th March 2015.

Isaac Newton Institute (INI) and the Newton Gateway to Mathematics.

54.   The INI[18] is a national and international visitor research institute. It runs research programmes on selected themes across the whole of the mathematical sciences with applications over a wide range of science and technology. It attracts leading mathematical scientists from the UK and overseas to interact in research over an extended period.

55.   The Newton Gateway to Mathematics[19] acts as a knowledge intermediary for the mathematical sciences. It is the impact initiative of INI. Supported by INI and the University of Cambridge, the Newton Gateway to Mathematics reaches out to, and engages with, the users of mathematics – in industry, business, public sector, and other scientific disciplines. It helps to bridge the gap between those engaged in frontier mathematical research and those working in more applied areas, by stimulating the interchange of knowledge and ideas. The INI (and therefore the Gateway) is a Department of the University of Cambridge with charitable status.

International Centre for Mathematical Sciences (ICMS)

56.   ICMS[20] stimulates and promotes the mathematical sciences through diverse international workshops and conferences. Its events programme attracts leading mathematical scientists from the UK and internationally - connecting mathematical communities across the world. Through its KE activity and academic support, ICMS connects workshops with the industrial and public sectors, hosts study groups and online KE activity such as V-KEMS, and has new follow-on funding to test emerging ideas via short projects. ICMS is a component part of the mathematical sciences departments of the Universities of Edinburgh and Heriot-Watt with charitable status.

Heilbronn Institute for Mathematical Research (HIMR)

57.   HIMR[21] supports mathematics in the UK through Research Fellowships and sabbatical opportunities for mathematicians and data scientists, and through a programme of conferences, workshops, and focused research activities.

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[18] https://www.newton.ac.uk/
[19] https://gateway.newton.ac.uk/
[20] https://www.icms.org.uk/
[21] https://heilbronn.ac.uk/

Chapter 6: Operations, governance, and relationship with other bodies

58.   There is a great deal of excellent activity and good practice across the organisations cited in the previous chapter. It is not possible, however, for any one organisation to deliver the breadth of activities set out in the proposition.

59.   It may not be necessary or even desirable to create a new organisation, or organisations, to deliver the outcomes (set out in Chapter 4) of the CCN. No one organisation has the coverage, or set-up to achieve all these many outcomes on their own.

60.   The primary function of the CCN should be to coordinate the outcomes set out in Chapter 4 by running them as **projects** in appropriate organisations. For example, it can be envisaged that the *creating capacity* project will require some support from UKRI; therefore the appropriate place for that to be run from would be a research organisation.

61.   The table below summarises the structures we believe are most appropriate for each CCN project:

	Delivery structure	Justification
Creating a voice for practitioners and end-users	Private/research organisation	Hosting forums could effectively be run by either, this is a coordination function requiring a dedicated team.
Creating mobility	Research organisation	Requires the relationship with university departments inc. managing placements. For the most part, the ability to draw on UKRI funding would be a prerequisite.
Creating capacity	Research organisation	Requires access to significant grant funding, therefore the structure needs to facilitate the hosting, and managing of, early-career researchers.
Developing skills	Private/research organisation	This a coordination function and could be run effectively by either.
Low-risk, high-reward entry points	Private	This involves the interchange of finance between multiple organisations and stakeholders. The organisation's independence is seen as valuable. As such, a private entity is most appropriate.
Brokering connections	Private/research organisation	The brokerage of connections could be (and is) effectively run by both. Good practice to be drawn from both.

62.   These projects would be fulfilled by researchers, practitioners, end-users, and professionals, with the management of the projects being led by the appropriate organisations described above. A novel part of this proposition is the creation of a central structure comprising the expertise and resource of the mathematical sciences infrastructure to support the end-to-end delivery of KE opportunities. The roles and relationships of all of these parties are expanded upon below.

Relationship with universities and researchers

63.   It is essential that all UK mathematical sciences departments have equal opportunity to engage in the CCN activities. One early suggestion of how to create this inclusivity was to create a regional sub-structure of the mathematical sciences departments. After detailed discussions with stakeholders this was felt, however, not to reflect a modern way of working.

64.   Instead, we propose a model where each department is invited to provide a **Mathematical Sciences KE Champion** to lead that department's engagement with the CCN. These champions will constitute a national **KE Champion Congress.**

65.   KE Champions will be members of the CCN projects, providing their expertise and good practice to the delivery of the wider group. In return, the CCN will work with the KE Champions at a departmental level to understand their bespoke requirements and opportunities for support in their KE ambitions. The KE Champions will meet annually to share success and disseminate progress of the CCN.

66.   Whilst the proposition here is to create a range of projects run through a number of organisations to achieve the various outcomes, the added value of the CCN is in the coordination, oversight, and central management of these projects, linking together opportunities and providing an end-to-end approach. As such, we describe the CCN in terms of **CCN Central** and **CCN Projects**. This is shown in the figure below.
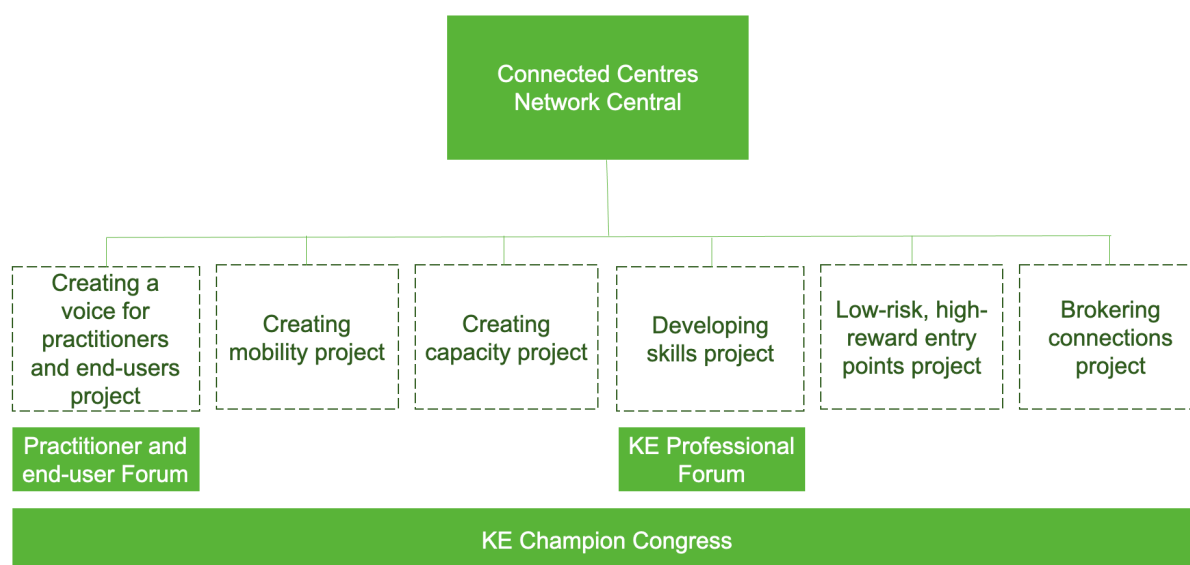
67.   Each project would be run out of (possibly) separate organisations, depending on where it makes most sense to deliver them from; most likely the mathematical sciences infrastructure. Each project would have a separate advisory structure (drawn from the KE Champion Congress).

68.   Each project will operate under an ED&I policy to be defined by CCN Central. As well as consideration of protected characteristics, and career stage, membership of each project must include at least one academic, one practitioner/end-user, and one KE professional.

Relationship with practitioners and end-users

69.   The **Practitioner and end-user Forum** is vital for creating dialogue between practitioners/end users and researchers. This forum would discuss opportunities around sector trends, pre-competitive challenges, particular scientific topics, SME engagement etc. This dialogue would ensure CCN activities are aligned with these various needs and priorities. This forum would be convened as part of the 'creating a voice for practitioners and end-users' project.

Relationship with KE professionals

70.   KE Professionals are an essential part of successful mathematical sciences KE. The **KE Professional Forum** will share good practice, experience, and appropriate opportunities for KE. The forum could allow for groups with less KE experience to learn from those with deep expertise and experience in mathematical sciences KE. This forum would be convened as part of the 'developing skills' project.

Relationship with mathematical sciences infrastructure

71.   The Newton Gateway and ICMS have extensive experience and expertise in mathematical sciences KE. Their contribution is critical to the success of the CCN, as are shared strategies for work delivery to ensure optimal operations. It is expected that as well as leading several projects they will have a significant role in the governance and oversight of the broader CCN initiative.

72.   Many of the CCN activities are coordination roles, and as such can be initiated with the new CCN appointments in the INI, and from the existing mathematical sciences infrastructure. Other activities will require new funding streams to be realised. This is expanded upon in Appendix 2.

Governance and oversight

73.   Below we have indicated how projects might operate under the CCN Central, with a particular focus on the roles and relationships needed to deliver them. The diagram below offers more detail on the CCN Central and Projects figure shown previously.
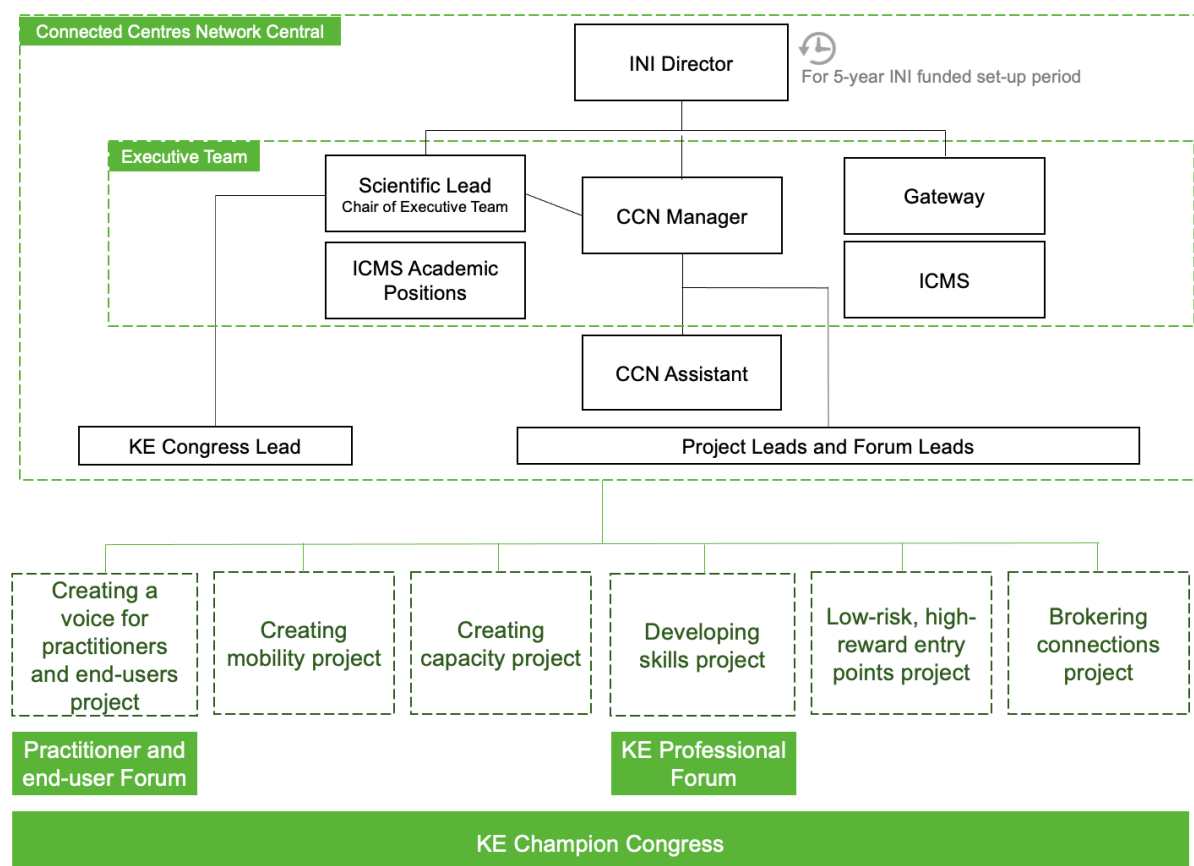
74.   The Executive Team will focus on operational oversight and day-to-day management of CCN operations and activities, and will meet roughly fortnightly. It will be comprised of the Scientific Lead (acting as Chair), the CCN Manager, Gateway and ICMS officers, and ICMS Academic(s).

75.   CCN Central will be a group composed of the Executive Team, the CCN Assistant Manager, the six Project and two Forum Leads, and the INI Director. CCN Central shall be chaired by the Scientific Lead.

76.   CCN Central will be charged with monitoring progress against the projects, offering support in delivery of the activities, and providing strategic and scientific input into the CCN and connectivity between the various projects. It will also consider broad issues around collaborative engagement, such as IP and commercialisation. CCN Central will create an ED&I policy that ensures fairness and equality of opportunity, and will underpin all of the CCN activity. CCN Central will meet formally on at least a quarterly basis.

77.   When the projects commence, a Lead for each will be chosen. An early task will be, for each project, to develop terms of reference, a workplan (including dissemination),

and milestones. This workplan will be discussed with the Executive Team and a delivery plan developed. This delivery plan should seek to complement the work done by the mathematical sciences infrastructure. Once agreed, resource and support will be allocated/offered by the Executive Team to achieve the delivery plan. Decision making within the projects will be undertaken by a quorum of the membership and approved by the Lead.

Staff

78.   INI received EPSRC Additional Funding Programme for Mathematical Sciences in 2020[22], and has allocated part of this to initiate the conception and set-up phases of the CCN. This money can be used towards the support of:

- **A Scientific Lead [0.5 FTE]** – part time senior academic appointment to work with the CCN Manager to develop a strategy and then to drive activity to deliver the CCN vision. To advocate externally for CCN growth and sustainability.
- **A Connected Centres Network Manager [1 FTE]** - to deliver the strategy of the CCN. To work with the projects, executive and national mathematical sciences community to ensure connectivity across the themes, identify new opportunities for the CCN, and provide effective project management.
- **A Connected Centres Network Assistant [1 FTE]** - to support the executive team in all administrative matters.

79.   The Newton Gateway is a trusted broker and knowledge intermediary for the mathematical sciences, and has provisionally allocated resource to the Connected Centres Network initiate to commence after the consultation period.

- **Gateway [0.2 FTE]** - to advise on professional KE delivery matters, to help support and/or coordinate the running of activities across the projects where required.

80.   ICMS is committed to supporting Knowledge Exchange in the mathematical sciences. Accordingly, ICMS has provisionally allocated resource to the Connected Centres Network initiative to commence after the consultation period. ICMS will be steered/guided by the community feedback regarding how to best support the CCN[23].

- **ICMS Academic Position(s) [0.2 FTE]** - to work with the Scientific Lead to develop and monitor CCN growth. To act as advisor(s) on the Executive Team on scientific and strategic matters.

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[22] https://www.ukri.org/news/funding-boost-for-mathematical-sciences-institutes/
[23] Personal communications with the then ICMS Director, 20/8/21

- **ICMS**[24] **[0.2 FTE]** - to advise on professional KE delivery matters, to help support and/or coordinate the running of activities across the projects where required.

81.   Additionally, the CCN will seek to engage the support, shared expertise and resources from other areas of the mathematical sciences infrastructure to ensure mutual alignment and benefit.

82.   The functions of the additional parts of the CCN Central, illustrated above, are outlined, along with indicative time commitments[25], as follows:

- **Project Leads [0.1 FTE]** - to coordinate the project projects, and work with CCN Central for the delivery of project objectives.
- **KE Champion Congress Lead [0.1 FTE]** - A co-opted member of the KE Champion Congress to provide continuity with the Congress.
- **KE Practitioner and end-user Forum Lead [0.1 FTE]** - this Forum will be run as part of the 'creating a voice for practitioners and end-users' project. It will likely run sub-groups of sector/discipline/regional importance.
- **KE Professional Forum Lead [0.1 FTE]** - this Forum will be run as part of the 'developing skills' project. It will focus on the topics which KE professionals wish to explore.

Relationship with the National Academy for Mathematical Sciences

83.   Eventually, as the National Academy for Mathematical Sciences develops and grows, it is envisaged that some assembly of the CCN Central and Project teams would naturally adopt the role of the Academy's Community Affairs Committee.
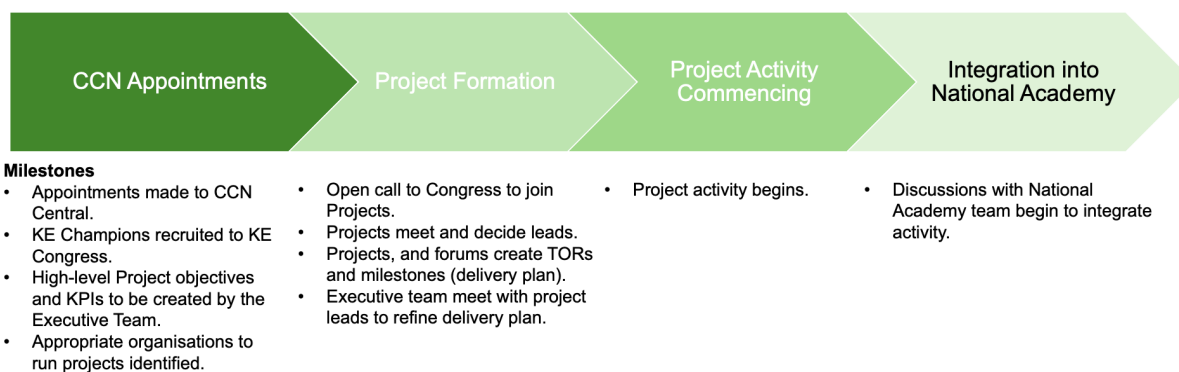
Roadmap

84.   The diagram below shows a high-level plan and order for how the various aspects discussed above might be structured.

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[24] Note that ICMS delivered activities would be eligible for Post KE event delivery support: https://www.icms.org.uk/knowledge-exchange
[25] Which is expected, in the first instance, to be funded by the individuals' host institution.

CCN Appointments	Project Formation	Project Activity Commencing	Integration into National Academy

Milestones

- Appointments made to CCN Central.
- KE Champions recruited to KE Congress.
- High-level Project objectives and KPIs to be created by the Executive Team.
- Appropriate organisations to run projects identified.

- Open call to Congress to join Projects.
- Projects meet and decide leads.
- Projects, and forums create TORs and milestones (delivery plan).
- Executive team meet with project leads to refine delivery plan.

- Project activity begins.

- Discussions with National Academy team begin to integrate activity.

85.   The CCN will be evaluated in its delivery of the above milestones by the Chair. Additional KPIs and milestones will be agreed by the Project Leads and the Chair to be evaluated on a regular basis as the projects are underway.

Consultation questions

86.   The authors would value feedback from the wide community of researchers, practitioners, end-users and KE professionals at this stage to develop the final version of this proposal for delivery. We would be pleased to hear any thoughts you have, but ask specifically that you consider the following questions.

- Which aspects of the proposal appeal to you most?
- Are there any activities missing?
- Which activities should be prioritised, and why?
- Are you content with the CCN structure and are there ways to make it more inclusive?
- For business, industry, and government: are the mechanisms for engagement appropriate, and end-to-end?

We seek your input on these questions by the 21st January 2022. Please complete the following short form: https://tinyurl.com/CCN-KE-Response

Should you have any specific queries please email connected.centres@newton.ac.uk

Annex 1. Acronyms

APTS	Academy for PhD Training in Statistics
ATI	Alan Turing Institute
CCN	Connected Centres Network
CDT	Centre for Doctoral Training
CPD	Continuing Professional Development
ECR	Early Career Researcher
ED&I	Equality, Diversity & Inclusion
EPSRC	Engineering and Physical Sciences Research Council
ESGI	European Study Groups with Industry
FTE	Full Time Equivalent
HEI	Higher Education Institute
HIMR	Heilbronn Institute for Mathematical Research
HoDoMS	Heads of Departments of Mathematical Sciences
ICASE	Industrial Cooperative Awards in Science & Technology
ICMS	International Centre for Mathematical Sciences
INI	Isaac Newton Institute for Mathematical Sciences
IP	Intellectual Property
KE	Knowledge Exchange
KTP	Knowledge Transfer Partnership
NATCOR	National Taught Course Centre in Operational Research
NCUB	National Centre for Universities and Business
PDRA	Postdoctoral Research Associates
REF	Research Excellence Framework
RSS	Royal Statistical Society
SG	Study Group
sKTP	Shorter Knowledge Transfer Partnership
SME	Small and Medium Enterprise
SPF	Strategic Priority Fund
TOR	Terms of Reference
SWOT	Strengths, Weaknesses, Opportunities, Threats
UKRI	UK Research and Innovation
V-KEMS	Virtual Forum for Knowledge Exchange in the Mathematical Sciences

Annex 2: Outcomes achievable by the CCN

87.   Following consultation with the various stakeholders, the text below articulates the benefits that could be achieved by the CCN proposition. The list below is referred to as the 'outcomes' within this document.

88.   Each outcome has been researched as to how it is (or historically has been) delivered through a variety of mechanisms. These mechanisms are assessed using a Strength, Weakness, Opportunity, and Threat (SWOT) analysis; for this we define:

- **Strengths** - what is good about the mechanism, and what is good about the way the UK supports it?
- **Weaknesses** - what is not so good about the mechanism, and what are the weaknesses in the way the UK supports it?
- **Opportunities** - what are the positive things which could happen if we address the weaknesses?
- **Threats** - what are the negative impacts of not addressing the weaknesses?

89.   The opportunities arising from this analysis for each outcome are collated in Chapter 5 as the combined opportunities (added value) that the CCN proposition offers – this then is the **mission for the Connected Centres Network.**

90.   It should be noted that routine data collection on the mathematical sciences uptake for some of the mechanisms listed below is patchy. It may be a role of the CCN to take ownership of this, so as to intervene with appropriate and timely measures.

A.1 Creating a voice for practitioners and end-users

91.   The need for mathematical scientists to engage in KE extends beyond those in academia. There is a vast, uncoordinated, and untapped community of excellent mathematical scientists in business, industry, and government. Additionally, many of those the CCN needs to interface with are not mathematicians, but end-users.

92.   There are currently a number of forums for practitioners and end-users to engage with each other and with mathematical scientists in university; these include committees in the learned societies, advisory structures for Institutes and research programmes, to name a few.

93.   Very often, the need from a practitioner or end-user does not sit neatly within the confines of a specific learned society committee, or cannot be addressed by one sub-discipline of the mathematical sciences. As such, there is a need for forums of practitioners and end-users which interface across disciplines and enable access to KE from wherever it is most appropriate to obtain it.

94.   These forums might focus on regional priorities, sectoral projects (e.g. automotive, retail), national or international challenges, or some identified technical subjects (e.g. uncertainty quantification, cyber security). Whilst there are many organisations who do this job effectively, the link with the other delivery mechanisms of the CCN will add great value.

95.   A recent example of where such a forum has been successful is the Newton Gateway's programme of 'Mathematical Challenges in the Electromagnetic Environment'[26]. The purpose of this activity is to create and nurture a community of researchers across disciplines to provide mathematically-led solutions and insights into challenges around the congested and contested EM spectrum. Ideas arising from this multidisciplinary forum can evolve into funded projects or studentships.

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[26] https://gateway.newton.ac.uk/node/10197

Strengths	Weaknesses
The UK is home to many organisations - large and small - who employ mathematical scientists. There are also a number of national organisations who convene practitioners and end-users to allow a multi-way conversation on mathematical sciences.	There are few forums for practitioners and end-users to access a wide range of research scientists to address their multifaceted needs. Additionally, spaces for practitioners and end-users to discuss pre-competitive challenges are often not focussed on the mathematical sciences.
Opportunities	**Threats**
The CCN could strengthen the mechanisms for practitioners and end-users to a) access the breadth of mathematical sciences needed to support their work and b) enhance their ability to engage in pre-competitive mathematical sciences challenges.	Without adequate provision, practitioners and end-users could fail to access the science they require. In addition, responses from academia to pre-competitive challenges remain unaddressed or only addressed in scientific silos.

A.2 Creating mobility

96.   People are the main currency of successful KE. There are a variety of mechanisms which enable researchers at all career levels to spend a defined period of time on internships, placements or secondments, in business, industry or government, and vice versa (i.e. end-users and practitioners spending time in universities). These are explicitly mentioned in four of the Bond Review Recommendations[27].

97.   We review existing schemes (or those which have successfully run in the past), which we know of, recognising that this list is unlikely to be exhaustive.

Shorter KTPs / industrial placements / internships

98.   Industrial placements or internships are a mechanism for PhD students to spend a few months embedded within a company working on a standalone project. The KTN for Industrial Mathematics ran the successful Short Knowledge Transfer Partnerships (sKTP) programme, prior to 2014, comprising 3 - 6 month internships[28].

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[27] Recommendations 7, 9, 12, 13 in particular[1]
[28] https://www.mathscareers.org.uk/article/industrial-mathematics-case-studies/

99. More recently, the University of Oxford's Centre for Doctoral Training (CDT) in Industrially-Focused Mathematical Modelling (InFoMM) has shown there is large demand for this type of mechanism: over a 6 year period, InFoMM partners collectively offered 220 projects.

Strengths	Weaknesses
For the student, they provide valuable experience of applying mathematical sciences to real-world industrial challenges. For the company they provide a short-term low-risk investment in the mathematical sciences and offer an excellent recruitment opportunity.	Can be an administrative burden to the host university. Since the Industrial Maths sKTP were discontinued, this type of opportunity is mostly only available to CDT PhD students.
Opportunities	**Threats**
The CCN could coordinate a national programme that is open to PhD students and ECRs from any HEI. It could help source industrial challenges, and broker academic supervisor expertise if not available in the same HEI as the researcher. An annual internship showcase event could help cement relationships and seed new ones.	The large pipeline of mathematical sciences students who pursue their careers outside of academia are at risk of not being well-trained towards working in industrial settings.

Knowledge Transfer Partnerships (KTPs)

100. The Knowledge Transfer Partnership (KTP) scheme helps businesses in the UK to innovate and grow. It does this by linking them with an academic or research organisation and a graduate student[29].

101. A KTP enables a business to bring in new skills and the latest academic thinking to deliver a specific, strategic innovation project through a knowledge-based partnership.

102. The academic partner will help to develop the project, provide academic input and recruit a suitable graduate, known as an Associate. They will act as the employer of the Associate, who then works at the business premises for the majority of the project. The scheme can last between 12 and 36 months, depending on the project and the needs of the business.

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[29] https://www.gov.uk/guidance/knowledge-transfer-partnerships-what-they-are-and-how-to-apply

Strengths	Weaknesses
The KTP programme began in 1975, and is a well-established, well-structured, centrally managed KE mechanism.	This scheme has not been widely taken up by the mathematical sciences. Just 0.7% of all completed KTPs - and none of 766 KTPs currently in progress - list mathematics as the "Main knowledge/technology area involved in the Partnership"[30]. Funding for academic supervision is a maximum of 0.1FTE.
Opportunities	Threats
The CCN could raise awareness of Innovate UK's KTP programme amongst both the academic community and the forum of practitioners and end-users, and undertake matchmaking brokerage. Given additional funding, the CCN could support greater academic-time buyout for supervision, when required.	Mathematical sciences could lose out to other disciplines in accessing this large, highly visible, programme of support.

iCASE

103.   EPSRC Industrial Cooperative Awards in Science & Technology (iCASE) provide PhD studentship funding for 4 years, where businesses take the lead in arranging projects with an academic partner of their choice[31]. The student must spend at least 3 months on placement at the industrial partner.

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[30] http://ktp.innovateuk.org/search.aspx
[31] https://epsrc.ukri.org/skills/students/industrial-case/intro/

Strengths	Weaknesses
Excellent training experience, recruitment tool, and mechanism for building a long-term relationship between an HEI and a company.	The scheme is limited to companies who provide a financial contribution to EPSRC. Only 5-10% of all iCASE projects are estimated to have an element of mathematical sciences[32]. Four years is a long-term commitment, during which the company's priorities can change. iCASE students could be seen as 'second-class' PhDs in academia.
Opportunities	**Threats**
The CCN could raise awareness amongst the forum of practitioners, end-users and in particular iCASE holders (often not mathematicians) on the value of recruiting mathematical sciences PhD students via iCASE studentships. Additionally, the CCN could collate success stories of completed projects.	Mathematical sciences could lose its visibility with major industries who engage most deeply with UKRI.

Industry Fellowships - for exchange of academic staff and / or industrial partners

104.   We are aware of a number of models which exist for industry fellowships; however, it has not been possible to perform a SWOT analysis on these given a paucity of data. Uptake in the mathematical sciences is recognised, anecdotally, as small.

- Royal Society Short Industry Fellowships 3 - 6 months duration – postdoctoral researchers are eligible[33].
- Royal Society Industry Fellowships, up to 2 years FTE - only open to permanent staff[34]. These are for researchers to spend time in industry or end-users/practitioners to spend time in a university.
- Royal Academy of Engineering Industrial Fellowships, 6 months - 2 years - for mid-career academics and industrialists[35].
- Royal Commission of 1851 Industrial Fellowships[36].

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[32] Private communication from EPSRC.
[33] https://royalsociety.org/grants-schemes-awards/grants/short-industry-fellowship/
[34] https://royalsociety.org/grants-schemes-awards/grants/industry-fellowship/
[35] https://www.raeng.org.uk/grants-prizes/grants/support-for-research/industrial-fellowships
[36] https://royalcommission1851.org/fellowships/industrial-fellowships

Immersive Fellowships

105.   There is great benefit to all parties for increased collaboration between the mathematical sciences and other disciplines. An inter-departmental/inter-university exchange, secondment, or placement scheme would enable the initiation, or acceleration, of collaboration. Such a scheme has, in the past, been supported by the research councils. Current models that could inspire a new scheme include the University of Bath's Academic Fellowship[37] and the University of Warwick's REF Impact Leave programme[38].

Strengths	Weaknesses
Other disciplines are a rich source of interesting and important problems. Real-world challenges, by their very nature, are multidisciplinary.	Different research cultures and terminology are often a barrier to collaboration, and take time and effort to break down. To the best of our knowledge, there are presently no national programmes supporting interdepartmental secondments.
Opportunities	**Threats**
The CCN could develop a national programme of placements which will enable staff time to be bought out and help encourage, support, and grow interdisciplinary collaborations with mathematical scientists. It would simplify HEIs' participation, and help provide equal access to the mathematical sciences across the country.	Without interdisciplinary collaboration, grand challenges - such as climate change and the UN's Sustainable Development Goals[39] - which require subject-specific expertise from multiple disciplines may not be addressed sufficiently.

A.3 Creating capacity

KE Fellows

106.   Pioneered by the Heilbronn Institute for Mathematical Research (HIMR), and more recently adopted by the Oxford-Emirates Data Science Lab, postdoctoral-level researchers called fellows, split their time evenly between their own research, and short-to-medium-term projects with business, industry, or government. A flexible 'KE

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[37] https://imibath.ac.uk/imi-fellows/
[38] https://warwick.ac.uk/services/ris/researchstrategy/ref2021/reqimpactleave/
[39] https://sdgs.un.org/goals

Fellow' model would enable the sharing of knowledge and expertise between the mathematical sciences community, practitioners, and potential end users.

Strengths	Weaknesses
These roles help mathematical scientists develop excellent interpersonal skills, who have capacity to ensure that new opportunities are responded to quickly, and that projects can be fulfilled within tight commercial time frames.	Non-standard academic roles could be seen as inferior to more traditional Postdoctoral Research Associates (PDRAs) or fellowships. If working on a variety of different projects, it can be challenging for fellows to develop specialisms and/or progress their own careers. PDRAs may not be able to publish some of their findings due to confidentiality clauses surrounding their work. From a financial planning point of view, it is difficult to forecast projects a year in advance as part of annual budget-setting exercises.
Opportunities	**Threats**
The CCN could enable a national community of KE fellows. A sizeable group provides identity, and greater choice of projects assists matchmaking between fellows and industrial partners. The CCN could provide job security by underwriting KE fellows' contracts for a fixed period, as well as designing a framework for career progression, e.g. senior KE fellows providing mentoring or line management.	Without a capacity to see KE opportunities through from problem formulation to embedded knowledge, opportunities are lost, and out competed by day-to-day priorities. Without a concerted effort to support career development for these types of roles, they will continue to be seen as 'second class', or short-term, career options.

Mathematical sciences KE professionals

107.   The Bond Review highlighted the benefits of dedicated mathematical sciences KE staff who specialise in building long-term relationships between mathematical sciences researchers and business, industry, and government, recommending that, *"Universities should have dedicated teams in mathematics departments to act as facilitators and KE translators."*[1]

Strengths	Weaknesses
Specialist mathematical sciences KE professionals have been shown to add significant value to departments. These roles can include elements of translation, business development, account management, grant writing, and project management and involve liaison with multiple university central functions, e.g. HR, finance, technology transfer, legal.	Despite offering rewarding and productive roles, individuals are often employed on short-term contracts (as they are typically funded by grants which expire), the only form of training or CPD provided is 'on-the-job', and there is no formal career progression. For smaller mathematical sciences departments, the costs of hiring a full time equivalent KE role is prohibitive.
Opportunities	**Threats**
The CCN could enable a national, pooled, distributed critical mass of specialist mathematical sciences KE professional staff - to advise, support, and broker relations - whose expertise could be accessed by any department. This would allow academic staff to focus on the technical aspects of projects, as well as supporting KE activity in smaller departments. In parallel to the KE Fellows, the CCN could design a framework for career progression. This would require access to significant resource, potentially through UKRI. These KE professionals could be based across the country and coordinated by the CCN.	Initiating and managing industrial relationships and projects are very time-consuming activities which can take academics' time away from the mathematics of the project, or, at worst, be a barrier for participation in the first place. The skills required do not always fall within academics' skill sets, and potential collaborations can be lost through relationships not being nurtured.

A.4 Developing skills

108.   Here, we consider the types of training initiatives the CCN could support to build up KE expertise and critical mass. The text below covers skills for students, researchers, practitioners, end-users, and KE professionals, which include:

- problem scoping and formulation;
- communication skills;
- commercialisation skills;
- technical skills; and
- KE skills.

Problem scoping and formulation

109.   *Target audience: Mathematical sciences students:* real industrial challenges are often very qualitative, and require a good deal of 'pre-processing', via communication with

the challenge holder, to be able to get to the stage where an industrial challenge can be formulated as a mathematical question. To familiarise students with problem-scoping techniques, the idea of a mathematical modelling week (or camp) was devised, and they provide an invaluable precursor to engagement in Study Groups.

Strengths	Weaknesses
Mathematics offers a language and a set of tools/skills, which can be used to understand a wide range of complex phenomena, processes, or data from any sector. The UK is an acknowledged leader in mathematical modelling[40]	Only a small number of mathematical sciences degrees in the UK use real, rather than idealised, problems as part of their teaching material. In the UK, currently two mathematical modelling weeks are organised per year - one in ICMS (in conjunction with Heriot-Watt and Edinburgh)[41] and one by the Newton Gateway[42] (formally run by Oxford), though these workshops are typically oversubscribed.
Opportunities	**Threats**
The CCN could make best-practice training in problem-based case studies (such as the University of Bristol's Department of Engineering Mathematics' 'Maths and Data Modelling'[43]) and modelling weeks more widely available. It could encourage greater participation in the international (online) mathematical modelling competition[44] for undergraduates, potentially with preparatory training sessions[45]. The CCN could run additional mathematical modelling weeks.	There is a long-term impact on the large numbers of mathematical sciences students who enter employment without the vital skills of problem formulation needed for addressing real-world 'dirty' problems.

Communication skills

110.   *Target audience: Mathematical sciences students and ECRs:* The ability to communicate mathematical ideas - both verbally and in writing - to a range of different audiences, including non-specialists, is a key element of successful KE. *"It is not enough to have a good idea; they [mathematicians] need to sell it in a language*

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[40] https://epsrc.ukri.org/newsevents/pubs/international-review-of-mathematical-sciences/
[41] https://www.icms.org.uk/events/workshops/ModCamp2021
[42] https://gateway.newton.ac.uk/event/tgmw91
[43] https://www.bris.ac.uk/unit-programme-catalogue/UnitDetails.jsa?ayrCode=20%2F21&unitCode=EMAT30005
[44] https://www.comap.com/undergraduate/contests/mcm/index.html
[45] http://maths.nuigalway.ie/cstudents/MCM11.shtml

management will understand."[46]. The InFoMM Industrial Enrichment Programme is an excellent example of how this training can be delivered[47].

Strengths	Weaknesses
Mathematical scientists are very analytical, and can use their skills to quickly get to the heart of a problem.	At school and undergraduate level, mathematical sciences is typically taught as an 'attention-to-detail' subject, and as a result, it can be challenging for mathematical scientists to focus on the big picture, rather than 'right answer' or 'perfect' solution. It is important to remember that even a negative result or a very simple model can have great practical value.
Opportunities	**Threats**
The CCN could promote and/or run transferable skills training courses, such as the Royal Statistical Society (RSS) 'Consulting Skills' course. It could coordinate 'boot camps' as part of a suite of learning activities (including talking with industry, how to give presentations, how to communicate effectively, etc.) in order to be credible when working with a company. This bespoke mathematical sciences KE training could potentially replace part of compulsory generic graduate school training.	Valuable insights available through mathematical sciences KE go unheard. Mathematical sciences graduates working outside of academia are less likely to be involved in decision making, and/or promoted as quickly, as their peers.

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[46] https://archive.siam.org/reports/mii/2012/report.pdf
[47] https://www.maths.ox.ac.uk/study-here/postgraduate-study/industrially-focused-mathematical-modelling-epsrc-cdt/infomm-course-5

Commercialisation skills

111.   *Target audience: Mathematical scientists at all career levels.* The vast majority of mathematical sciences graduates will find themselves working in a commercial environment. Training and preparation in commercial practices are vital.

Strengths	Weaknesses
Mathematical Scientists often have innovative ideas which have the potential for commercialisation.	Entrepreneurial skills, such as how to develop a business plan and pitch ideas for investment, are an extremely rare feature in mathematical sciences training in the UK.
Opportunities The CCN could raise greater awareness of existing, well-regarded, programmes such as the Young Entrepreneurs Scheme (YES)[48], open to postgraduate students and ECRs, and SetSquared's Innovation to Commercialisation of University Research (I-CURE)[49], or, given additional funds, develop its own programme.	**Threats** Mathematical sciences students could be entering the workforce without an appropriate realisation for how organisations utilise or exploit research.

Technical skills

112.   *Target audience: practitioners and (potential) end-users:* Preliminary market research, carried out for the Newton Gateway in early 2020, indicated there was strong demand for CPD in areas such as Operations Research and Machine Learning. National graduate courses, such as the Academy for PhD Training in Statistics (APTS)[50], and NATCOR's Operational Research and Business Analytics courses[51] - are highly-respected, and help provide PhD students across the country with equal access to training opportunities.

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[48] http://www.yescompetitions.co.uk/
[49] https://www.setsquared.co.uk/programme/icure-programme-2/
[50] https://warwick.ac.uk/fac/sci/statistics/apts/
[51] http://www.natcor.ac.uk/

Strengths	Weaknesses
Most of the material required for such courses can be found in many existing undergraduate or postgraduate degree courses.	This material is not typically packaged for short (several day) industrial training courses.
Opportunities The CCN could learn from the successes of APTS and NATCOR, and expand their reach. Training courses - especially if Continuing Professional Development (CPD) accreditation is possible - could provide a valuable income stream for the CCN. They also offer an attractive proposition for new industrial partners to engage with the CCN for the first time, providing a stepping stone for other forms of engagement.	**Threats** Failing to provide training opportunities with practitioners and end-users could widen the disconnect between university researchers and those outside of academia.

KE skills

113.   *Target audience: KE professionals, and academics with leadership responsibilities, or interest, in KE.* There are professional bodies who provide training and guidance in KE and technology transfer. Access to these skills and training are vital for initiating and managing KE projects effectively.

Strengths	Weaknesses
There are a range of relevant training courses currently available nationally, including highly-respected training courses run by PraxisAuril, the UK's professional association for KE practitioners, in areas such as KE, business development, technology transfer, university consultancy, and strategic relationships[52].	Typically, the only form of training or CPD provided is 'on-the-job', and there is no formal career progression. Academics with KE leadership responsibilities (or interest) are typically not given sufficient recognition for their time invested.
Opportunities	**Threats**
The CCN could develop professional mathematical sciences KE training, both for dedicated KE staff and academics with KE leadership responsibilities. Anecdotally[53], the mathematical sciences community seems largely unaware of PraxisAuril[54]. In the long term, greater course uptake could lead to more Registered Technology Transfer Professional (RTTP) accreditations - the international professional standard for KE practitioners[55]. The CCN could work with professional societies to provide recognition through prizes for excellence in KE[56].	Without effort to support those professionals who facilitate and manage the interaction between mathematical scientists and those wishing to engage in KE, opportunities can be lost. This can happen in a variety of ways: KE talent can be lost through a lack of career progression, potential collaborations can be lost through incorrectly handled leads etc.

A.5 Low-risk, high-reward entry points

Study Groups with Industry

114.   Study Groups with Industry are an internationally-recognised method of KE between academic mathematical scientists and industry. These week-long workshops provide a forum for industrial scientists to work alongside academic mathematicians on problems of direct industrial relevance[57]. These workshops begin with industrial challenges being presented and are followed by small groups forming to provide fast solutions to these challenges.

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[52] https://www.praxisauril.org.uk/training
[53] c.f. IMA Employers' Forum: Knowledge Exchange, November 2019. https://ima.org.uk/12541/seventh-employers-forum-knowledge-exchange/
[54] https://www.praxisauril.org.uk/training
[55] https://www.praxisauril.org.uk/RTTP
[56] https://ima.org.uk/14663/ima-hedy-lamarr-prize-2021-call-for-nominations/
[57] https://ecmiindmath.org/study-groups/

115.   The success of the Study Groups' unique format, which uses problems presented by industry as a basis for mathematical sciences research, is demonstrated by the extent to which it has been copied around the world and is now extending into other areas where mathematics may be applied. The European Study Groups with Industry (ESGI) started with the first Study Group in Oxford in 1968 and now there are 5-7 meetings held across Europe every year, including an annual UK ESGI.

Strengths	Weaknesses
A UK model which has been exported internationally. Strong champions in the community. Benefits for various stakeholders recognised and advertised. Valuable training experience for further engagement in KE work.	Currently there is no formal oversight committee and participation is not very diverse. There is no formal business model, and the long-term impacts of ESGI participation are not routinely captured. The industrial 'experience' can vary; some reports are never written or take a long time to finalise, and follow up with companies is not systematic. There has also, until recently[58], never been a permanent repository and standardised format for the reports.
Opportunities	**Threats**
The CCN could offer a modest amount of additional structure to provide enhanced support for the UK ESGI experience, increasing the likelihood of positive experience and potential for long-term collaborations. A permanent website[59], account management, and a standardised process for capturing long-term impact and results of participation, would be valuable resources. A realistic business model, which costed academic and professional staff time would aid sustainability.	Variable experience of ESGIs leads to reputational damage. Lack of diversity affects growth. Lack of a body of evidence of ESGI benefits threatens their future.

Shorter/themed Study Groups

116.   The success of the ESGI model in the UK has spawned a plethora of shorter, sector-focussed Study Groups[60], either organised by parts of the mathematical sciences national infrastructure or in individual departments.

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[58] The recent Mathematics in Industry Reports (MIIR) series, hosted by Cambridge University Press, offers a permanent repository for ESGI reports https://www.cambridge.org/engage/miir/public-dashboard

[59] https://www.swi-wiskunde.nl/swi2020/

[60] https://ima.org.uk/13128/study-groups-with-industry-what-is-the-value/

117.   The formats of these shorter Study Groups vary widely, they can be run as part-day or multi-day activities. The problem providers could be from a single organisation, or from multiple companies in the same or different industrial sectors.

Strengths	Weaknesses
These shorter sessions, often themed by a particular sector, and recently undertaken in a virtual setting, have been successful in recruiting a wider range of mathematical scientists. Additionally, the costs for these sessions are much reduced, meaning that new industrial entrants can be brought into the mathematical sciences KE world with a relatively low (if not zero) cost. The Alan Turing Institute (ATI) has also been running successful Data Study Groups for a number of years now[61].	Shorter, cheaper, sessions have the danger of undercutting the 5-day session. There is not a clearly articulated value statement and justification for what an industrial organisation might expect to receive from the various different-length SGs. Also, the calendar in the UK is very busy with these sessions, hence there is a danger of burnout from a small community of researchers, practitioners, and end-users.
Opportunities	**Threats**
The CCN could provide additional support for the delivery of smaller Study Group sessions alongside the UK ESGI. It could coordinate timings, problem allocation, and follow up, as well as diversifying the industrial, participant, and host institution involvement by using these smaller more flexible sessions. It could also create a good-practice handbook/training for running shorter SGs, especially in smaller departments, and provide a small funding pot to allow departments to involve SMEs.	An uncoordinated approach to the many SGs being operated risks an overall diminishment of the brand, and otherwise general fatigue without a proper articulation of the various impacts and results of the various formats.

A.6 Brokering connections

118.   There are a number of organisations which participate in the brokerage and 'making-connections' space. The primary mechanisms for these are through events which allow mathematicians, practitioners, and potential end-users to engage with each other.

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[61] https://www.turing.ac.uk/collaborate-turing/data-study-groups

119.   There are three ways by which we describe brokerage:

- One-to-one brokerage,
- One-to-many brokerage, and
- Many-to-many brokerage.

One-to-one brokerage

120.   Finding the best person in the mathematical sciences who is working in the area and who could help solve a problem or provide insight is challenging. A short discussion between the appropriate people can open the door to insight and further collaboration.

Strengths	Weaknesses
There are directories which exist to signpost people to expertise in the mathematical sciences and more broadly (e.g. the LMS Directory[62] and the NCUB Konfer tool[63]). One-to-one signposting is done to some extent by KTN, ICMS, and Newton Gateway.	Directories quickly become out of date and the language used may not lend itself to the mathematical sciences. Instead, informal contacts and networks are used, perhaps at the expense of the 'right' contact or diversity of available talent.
Opportunities	**Threats**
The CCN could develop a representative network across all UK mathematical sciences departments to quickly identify the 'best' people to signpost KE opportunities.	Reliance on informal and unrepresentative networks limits the diversification of KE opportunities.

One-to-many brokerage

121.   Where brokerage is required, but the nature of the insight needed has not been identified, a one-to-many 'translation' function is required. This translation requires people to work with a challenge provider to break it down into a suitable mathematical sciences problem. This is more time-consuming than a one-to-one signposting function.

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[62] https://www.lms.ac.uk/msdirectory
[63] https://konfer.online

Strengths	Weaknesses
The UK is home to many exceptional researchers who are highly skilled in translating 'real-world' industrial challenges into mathematical problems.	Problems are not ready formed into mathematical statements, and problem-owners are not always aware that the mathematical sciences have something useful to contribute. Translation of these problems into the mathematical sciences language is time-consuming, and ultimately the technical input required may not fall into the skillset of the person doing the initial translation.
Opportunities	**Threats**
The CCN could trial innovative methods for one-to-many brokering and translation. For example, extend the recent success with the Analysis for Innovators (A4i) and Innovation Exchange (iX) programmes with KTN and Innovate UK[64,65.] This could involve providing a 'front door' for practitioners and end users to bring their problems, which could be formulated into more mathematical questions by a group of experienced representative researchers, and subsequently brokered.	Opportunities for mathematical sciences KE are not translated and acted upon and/or leads are not shared amongst those in the community who are best placed to address them.

Many-to-many brokerage

122.　　Many-to-many activities (such as horizon-scanning events) provide opportunities for serendipitous interactions to occur. These meetings, which could be themed around a topic or an industrial area, are open environments designed for chance-interactions to develop.

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[64] https://www.a4i.info/
[65] https://www.ktninnovationexchange.co.uk/

Strengths	Weaknesses
The Bond Review highlighted events and networking opportunities as key KE mechanisms. Several institutions in the UK provide networking and events coordination for the mathematical sciences and its interface with business and the wider scientific community. INI, the Newton Gateway, and CMS have excellent track records in this area.	For the most part, these events are not 'joined-up' nationally, or matched with recommended follow-on mechanisms. Strategically important topics are not discussed in a connected manner. Long-term outcomes are difficult to capture. Specialist/smaller events are not given the same promotion and support as those from larger organisations.
Opportunities	**Threats**
The CCN could draw together a national calendar of events, which covers its self-initiated activities and also those initiated by other researchers, practitioners, KE professionals, and end users.	Mathematical sciences events will continue in an uncoordinated way. Large strategic topics will suffer from this lack of coordination, and events run by smaller groups will continue to lack visibility.

Resource consideration of proposed activities

123.   It is helpful here to describe what we think would be achievable under various scenarios of funding. From **low** (with no additional funding), **medium** (using some additional resource from the mathematical sciences infrastructure, leveraging small amounts from the KE Champion Congress), and **high** with large pots of new funding. This is shown in the table below.

124.   With a regular, modest amount of funding, the CCN could expand currently under-resourced, or initiate new, mechanisms. This money could come from income from CCN activities, or repurposed funding from the mathematical sciences infrastructure.

125.   With access to large amounts of funding from UKRI via routes such as the Strategic Priority Fund (SPF), Connecting Capability Fund etc, entirely new and ambitious programmes could be created by the CCN.

126.   The CCN would begin operations delivering the **Low** cost activities in the early months, and start to develop plans for accessing funds for the **Medium** scenario, and, in parallel, develop ambitious proposals to access the funding required to deliver the **High-level** scenario. This would be an early task for the projects.

Scale of delivery costs		
Low	**Medium**	**High**
KTPs	Shorter KTPs / placements	KE Fellows
iCASE	Technical skills	MS KE Professionals
Industry Fellowships	Problem scoping skills	
Immersive Fellowships	Communication skills	
UK ESGI enhanced support	Commercialisation skills	
Short Study Groups	KE Skills	
Many-to-many brokerage	One-to-many brokerage	
One-to-one brokerage		