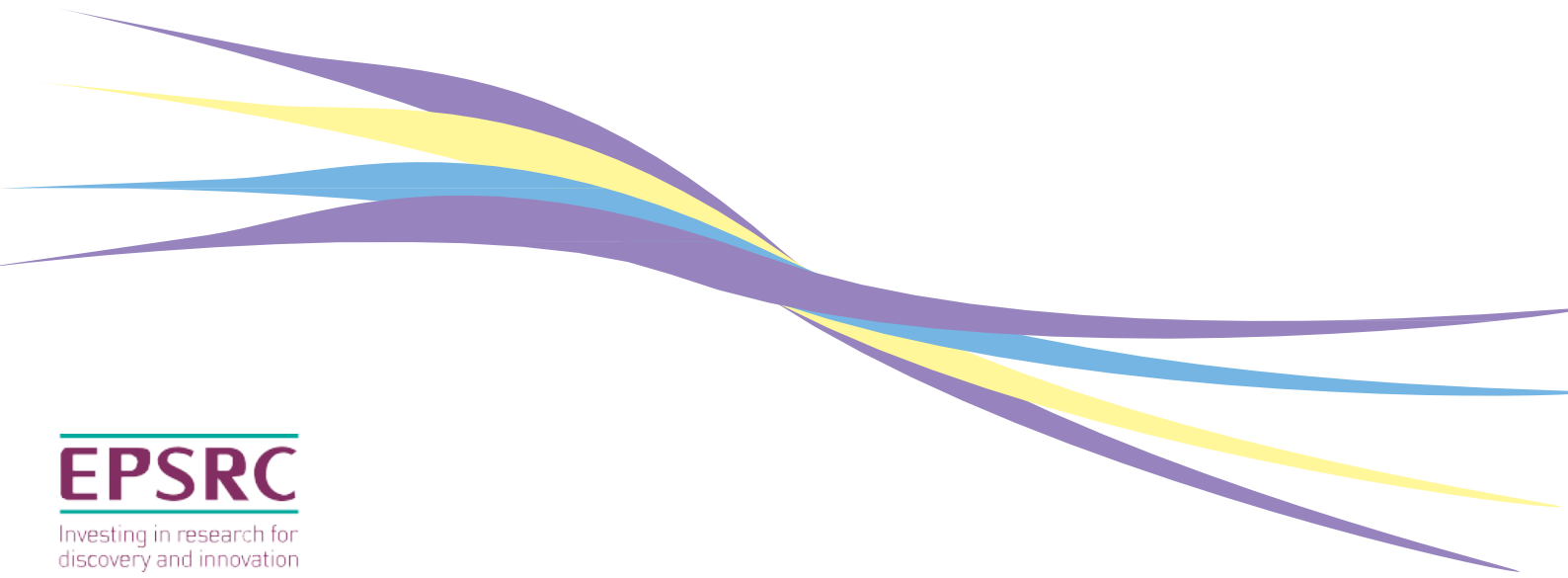
ENGINEERING AND PHYSICAL SCIENCES RESEARCH COUNCIL

# MATHEMATICAL PHYSICS EVIDENCE AND ENGAGEMENT WORKSHOP REPORT

Research, discover, innovate



EPSRC
Investing in research for discovery and innovation

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# CONTEXT

Balancing Capability is one of three strategies in our strategic plan and is an important part of managing our portfolio of investments. It aligns our portfolio to areas of UK strength and national importance. Our strategy has enabled us to champion excellence and invest in research of the highest quality in addition to securing better value for the taxpayer. Through this strategy, EPSRC supports a balanced portfolio that nurtures both discovery and challenge led research – a balance that is achieved through our engagement with business and government to influence, respond and adapt to a changing research landscape. Balancing Capability has continued to use the research area trajectories of 'grow', 'maintain' and 'reduce' and this approach will continue to enable EPSRC to balance our portfolio in line with national need.

## What is EPSRC doing now as part of the Balancing Capability strategy?

EPSRC are now reviewing the research area rationales to reflect how the research base has changed over the last five years. This will enable EPSRC to align these with future aspirations for the next five years.

## Why are we reviewing our rationales?

- Our original research area rationales were published in 2012 but the science landscape has continued to evolve and we need to ensure our rationales reflect this.
- We need to ensure we focus on UK strengths and nationally important areas so the UK remains internationally competitive and builds strength in areas with potential in terms of national prosperity.
- In our delivery plan, we have identified four interlinked Outcomes which collectively underpin UK prosperity: Productivity, Connectedness, Resilience and Health. We want to ensure that our research area rationales link appropriately to this outcomes framework.

The Mathematical Physics Evidence and Engagement workshop was held to build upon work EPSRC has already undertaken and to gather further evidence to support the review of our research area rationales and to provide the community with an opportunity to feed into shaping our research area strategies as we move into the next delivery plan period. The evidence gathered will form part of an evidence base which will inform the development of our research area rationales in implementing the delivery plan. In particular, the criteria of quality, capacity and national importance are being considered for all Research Areas across EPSRC.

The 'quality' of a research area includes the international standing of UK research, the transformative or disruptive potential of research in that area and whether the UK's capability in the area is unique in an international context. The 'national importance' of an area considers the potential impact of a research area on the current or future success of the UK economy or the development of key emerging industry(s). In addition, national importance could include an area of research making a clear contribution to meeting key societal challenges facing the UK. When considering the 'capacity' of an area, we are

interested in if there is a healthy population and profile of UK researchers of international standing active in the area and if there are suitable mechanisms for interdisciplinary working.

We also want to understand what the community's view of the key challenges, opportunities and interfaces will be in Mathematical Physics over the next few years. This evidence will help inform our thinking around our Balancing Capability strategy.

In summary, the outcomes of this workshop alongside the refresh of the EPSRC landscape documents, input from key stakeholders (such as learned societies etc.) and a subsequent call for evidence will be used to consider the future strategy of the Mathematical Sciences theme.

## OBJECTIVES

The objectives of the workshop were as follows;

- To analyse and contextualise the current UK landscape for Mathematical Physics.
- To engage with the community to discuss the direction of Mathematical Physics through the next delivery plan phase.

## DELEGATE SELECTION

During discussions with the Mathematical Sciences Strategic Advisory Team (SAT) it was proposed that attendees at the engagement workshop should be nominated by the Mathematical Sciences community. To facilitate this process more than 25 heads of department at academic institutions across the UK were contacted to submit up to 3 nominations for members of the academic community working in Mathematical Physics to attend the workshop. In order to achieve a balance of research interests across the breath of Mathematical Physics at the workshop, SAT members also advised on appropriate attendees. A full list of delegates can be seen in Appendix One.

# WORKSHOP PROCEEDINGS AND OUTCOMES

EPSRC representatives from the Mathematical Sciences, Physical Sciences and Building Leaders teams were in attendance, as well as a representative from STFC. These staff members were present to help facilitate each session and to answer any questions from community members.

An introductory session on the current Mathematical Sciences theme strategy and an introduction to the Balancing Capability process were provided by EPSRC. During this presentation, the aims and purpose of the event were made clear. The emphasis was made that EPSRC were there to engage with the Mathematical Physics community and to understand the community's perspective of the research area. It was also communicated that the outcomes and views from the workshop would feed into EPSRC's evidence base, which would be drawn upon for future strategic decisions. Following the EPSRC presentation, Professor James Vickers gave his perspective on Mathematical Physics in the UK and its successes. He also discussed some future directions for UK Mathematical Physics.

The facilitated part of the workshop was divided into 3 sessions investigating the current research landscape of Mathematical Physics and the future opportunities for the discipline.

Participants were lead through each session in small breakout groups. Time was also allocated at the end of the day to allow for open discussion of topics not already covered during the main sessions.

The facilitated discussions broadly focused on the following topics:

- Analysis of the Mathematical Physics research landscape to identify specific areas of strength, weakness, opportunity and threats (SWOT) to the health of the area.
- Analysis to determine current and emerging overlaps between Mathematical Physics and other areas of Mathematics. Further analysis to determine overlaps between Mathematical Physics and other disciplines (e.g. Physics, Physical Sciences, Materials Science, ICT).
- The refresh of the 2010 International Review of Mathematics landscape document for Mathematical Physics.
- Future opportunities for Mathematics Physics research and the research community.

The agenda for the workshop can be found in Appendix Two.

## SWOT Analysis of Mathematical Physics

In order to further our understanding of the current research landscape, attendees were asked to discuss what they believed the strengths, weaknesses, opportunities and threats were for Mathematical Physics. Attendees we also asked to group comments based on whether they relate to the quality, national importance or capacity of the area, as well as any evidence to support comments made.

The key messages from this session are summarised below with the complete set out of outcomes shown in Appendix Three.

- A key strength of the area is the high quality of researchers and research, evidenced by its success in obtaining ERC grants.
- The UK has a unique strength in its closeness of Mathematics and Physics.
- There are growing interactions between Mathematical Physics and Probability, Analysis, Geometry and Combinatorics.
- There is a lack of engagement with more direct applications.
- There is a concern around the stability of the people pipeline. Lack of CDTs in the area mean that PhD funding is reliant on the DTP. There are also too few postdoc positions.
- There are many interfaces with scope for new mathematical developments e.g. Quantum information, Statistics & Applied Probability, Nanotechnology, Network Science, Non-linear PDEs etc.
- Due to the different funding structures in EPSRC and STFC, it can be difficult working at the interface.

## Analysis of Inter/Intra Disciplinary Overlaps

Participants were asked to identify and explore connections between their current research community and adjacent areas of the EPSRC Mathematical Sciences taxonomy, as well as highlighting links to other disciplines. The intention of this activity was to identify areas which have emerging links or potential to link in the future whilst also considering areas where there is currently large overlap with substantial potential.

This exercise did highlight the extensive collaboration which is ongoing between Mathematical Physicists and other Mathematicians. In addition, it was emphasised that Mathematical Physics is inherently interdisciplinary by definition, so there exist many overlaps between Mathematical Physics and areas of Theoretical and Particle Physics. Even though there exists already a large degree of overlap between these areas it is clear there is a large amount of scope for new results at the interface between Mathematical Physics, Theoretical and Particle Physics. It was made clear that there is a high degree of fluidity between Mathematical Physics and the research areas of EPSRC taxonomy, expanding outwards to STFC's remit.

Highlights of both established and emerging intradisciplinary links (that is links from Mathematical Physics to other areas of mathematics) are documented below with the full documented outcomes included in Appendix Three.

- Numerical Analysis
- Mathematical Biology
- Mathematical Analysis
- Logic
- Combinatorics
- Non-Linear Systems
- Algebra

- Geometry & Topology
- Statistics & Applied Probability

Highlights of both established and emerging interdisciplinary links (that is links from Mathematical Physics to other disciplines) are documented below with the full documented outcomes included in Appendix Three.

- Cold Atoms & Molecules
- Quantum Optics & Information
- Condensed Matter Physics
- Quantum Technologies
- Chemistry
- Nuclear Physics
- Theoretical Physics
- Theoretical Astronomy
- Particle Physics
- Particle Astronomy

This session provided context for the links we know exist between Mathematical Physics and other research areas of the Mathematical Sciences taxonomy and beyond. These findings are critical to highlight the importance and impact that mathematical research has on adjacent disciplines. It was emphasised many times throughout the workshop that Mathematical Physics is almost unique in that it connects strongly to both pure and applied mathematics.

## Discussion of the Mathematical Physics Landscape Document 2016

In 2010 landscape documents were prepared for a range of research areas in mathematical sciences as part of the International Review of Mathematics (IRM). These documents have been a valuable tool for EPSRC to understand the research landscape in the Mathematical Sciences. In order to assess how the research landscape has changed since 2010, it was proposed that the landscape documents from 2010 be refreshed by the community to help understand how each research area in the mathematical sciences has evolved since 2010. The original landscape document authors from 2010 were approached by EPSRC to update the landscape documents to more accurately reflect the current research environment of the Mathematical Sciences. Two of the original authors for the Mathematical Physics landscape document, in collaboration with three suggested authors were invited to produce an updated view of the Mathematical Physics landscape and highlight any key changes in the area since 2010.

As part of EPSRC's ongoing engagement with the community, the landscape documents for Mathematical Physics, the applied mathematics research areas and the pure mathematics research areas have been updated. Finalised refreshed documents for all these areas will be used as a snapshot of the current landscape of each research area at a point in time. These documents will feed into the ongoing Balancing Capability process.

A draft version of the Mathematical Physics updated landscape document was discussed at the workshop in order to gain wider community input. Feedback from attendees was

generally very positive, with attendees commenting that the authors had done a good job of summarising all the sub-areas within Mathematical Physics. Several comments were made about expanding the section relating to future opportunities and directions for the area. Feedback from the event indicated that attendees very much valued this session, giving them the opportunity to feed into the landscape document and discuss the research area in general. It was emphasised that it is not a trivial task to try and define what Mathematical Physics encompasses. It was recognised that Mathematical Physics is a broad area interfacing with many other disciplines.

The landscape documents will be published on the EPSRC website following the incorporation of comments from attendees at the workshop and the wider Mathematical Physics community.

## Future Opportunities

The final session of the workshop focused on looking forwards to future opportunities for Mathematical Physics. The first part of the session looked at what would be the best and worst cases for Mathematical Physics in 5 years' time. The responses from attendees can be seen in the table below.

| Best case scenario for Mathematical Physics in 5 years | Worst case scenario for Mathematical Physics in 5 years |
|---|---|
| • Grow funding (or at least maintain)<br>• Sufficient number of Fellows to secure Mathematical Physics' future.<br>• Develop new interfaces with biology<br>• Early career researchers should be fostered<br>• Project studentships return<br>• DTP funds more studentships- healthy number of studentships.<br>• CDT in the area.<br>• CDT's don't dominate PhD funding.<br>• Increased PDRA funding.<br>• Closing gaps between funding agencies.<br>• Larger geographical spread of funding.<br>• Continue world leadership in many areas of Mathematical Physics.<br>• Interaction with non-academic user group- publicising Mathematical Physics- 1st construction of quantum computers<br>• Mathematical Physics is an idea factory- realising timescales | • Research is strangled by EPSRC priorities- loss of intellectual leadership.<br>• Mathematical Physics remains a 'reduce' under Balancing Capability.<br>• Maths budget decreases<br>• Funding gets focussed at a small number of people.<br>• Blue sky research is outsourced<br>• Reduce in funding Mathematical Physics continue- Universities divert appointments away from Mathematical Physics<br>• Maths departments become teaching departments<br>• PhDs concentrated in a small number of institutions<br>• Closure of INI, ICMS<br>• No new people<br>• Have to reinvent as other disciplines.<br>• UK stops attracting talent. UK already has a reputation for not having PDRAs- this would get worse.<br>• Worsening climate for fundamental |

| | |
|---|---|
| • Recognition of Mathematical Physics across EPSRC and the wider public.<br>• More time to develop speculative ideas.<br>• Access more top-down funding<br>• Sustained funding/support for key areas.<br>• Playing to strengths of area.<br>• No bottlenecks in supply (e.g. postdocs)<br>• Easier to interact with other disciplines.<br>• Maintain ERC funding to area.<br>• Increased number of prizes in Mathematical Physics<br>• Exploit opportunity of Quantum. | research.<br>• Universities chasing REF impact.<br>• Fewer PhDs- gets worse and worse.<br>• More ResearchFish.<br>• Increase in transferable training for PhD students. |

The second part of the session looked at trying to prioritise future opportunities for Mathematical Physics. These could be opportunities around particular interdisciplinary interfaces, key research challenges within the research area or opportunities related to challenges of UK national importance. Attendees highlighted the following as high priorities for Mathematical Physics in the next 5 years.

- Increase capability/capacity at all levels- PhD, PDRA through to Professorship.
- Focus on person, not necessarily project.
- ODA money- Newton fund and challenges, Research Infrastructure
- Grand Challenges- Sandpits
- Links to finance
- Use alumni better- Get recognition for provision of clever people to other places, Alumni networks would be effective.
- Big science e.g. Dark energy, dark matter, LHC, gravity
- Quantum- materials (spin chain systems), quantum memory storage (condensed matter, atomic densities), quantum fabrication, quantum cryptography
- Manufacturing- topological insulators, materials prediction and modelling
- Theory of computation
- Energy efficiency- materials, spin chains, dynamic skyrmions
- National security
- Maths Physics contribution to social sciences- crowd dynamics, brain science
- Virology
- Unified Theory of forces
- Rigorous justification of the Laws of Thermodynamics
- Foundations of Quantum Field Theory
- Emergence of SLE from deterministic models
- Precise understanding of Nuclear forces, Quarks and Gluons.

The final session of the workshop highlighted that there are many potential future research paths for Mathematical Physics to explore as well as opportunities related to student training

and the people pipeline. It was emphasised that the opportunities discussed in this session, as well as in the SWOT analysis session, should be explored and exploited to maximise the contribution Mathematical Physics can make to other disciplines.

## SUMMARY OF ISSUES RAISED

The workshop incorporated a discussion session which covered a range of topics. The discussion session began with a short talk from the EPSRC SAT Chair, Ken Brown, who highlighted several issues of importance to the mathematical community. These included the DTP and studentships in general, Fellowships, the Balancing Capability strategy, and the updated landscape documents from the 2010 International Review of Mathematics 2010.

A summary of the issues raised are discussed below:

- Balancing Capability was discussed at the CMS meeting with Chief Executive Phil Nelson and he suggested that the community make the case for supporting each research area of the Mathematical Sciences equally during the Balancing Capability process.
- Broad support for more Fellowships and the need for increasing support through this route should to be articulated to EPSRC.
- Are CDTs working for the mathematics community? Is the concentration of resources the right thing for studentships?
- DTP funding cut to Mathematical Sciences is a significant concern to the community and in the near future CMS plan to survey academic institutions to find out how the DTP allocation was awarded to Mathematical Sciences departments.
- The different funding mechanisms for EPSRC and STFC need to be further harmonised to avoid difficulties for academics at the boundary of the two research councils. EPSRC staff advised that anyone who feels they fall between the two Councils should make contact prior to submitting an application to check the remit of their proposal. EPSRC provides a remit query service to advise applicants on which Council would be most appropriate for their proposed research. https://www.epsrc.ac.uk/funding/howtoapply/basics/remit/remitqueries/

# NEXT STEPS

This event was seen by EPSRC as a platform to build upon our engagement with the Mathematical Physics community and the wider Mathematical Sciences community. Our aim is to ensure that the Mathematical Sciences community have had the chance to communicate with EPSRC regarding their area of research and to contextualise Mathematical Physics in the wider research landscape. Throughout 2016 and beyond EPSRC will be continuing to main a constructive dialogue with the research community, especially during the ongoing Balancing Capability process.

i. Prior to the Mathematical Physics workshop, EPSRC held two other engagement workshops. The first was focussed at engaging with the Pure Mathematics community and the second focussed on the Applied Mathematics community. Summary reports of both these workshops shall also be published.

ii. An engagement event to gather the community perspective on Statistics & Applied Probability is being planned to take place within the next 12 months.

iii. A recent event was held with the Operational Research community and a report for this event has been published.

iv. This report will be considered by the Mathematical Sciences SAT prior to publication and dissemination to the rest of the community. If the SAT highlights possible actions as a result of this report then they will be considered in due course.

v. The outcomes from the workshop alongside the community landscape documents will be incorporated into the evidence gathering stream for the Balancing Capability process to ensure a community perspective remains a key focal point during strategic discussions.

vi. Issues raised with regards to equality and diversity and support for early career researchers will be fed into ongoing strategic actions plans for each of these topics, which remain to be key foci for the EPSRC throughout the next delivery plan phase.

vii. As reiterated at the event this is one part of a developing engagement programme with the Mathematical Sciences community and numerous opportunities shall arise during the next 12 month period for interactions between EPSRC and the research community.

# FEEDBACK

Details of the feedback received can be viewed in Appendix Four.

# APPENDIX ONE – DELEGATE LIST

| | |
|---|---|
| John Barrett | University of Nottingham |
| Harry Braden | University of Edinburgh |
| Ken Brown | LMS/ University of Glasgow |
| Ed Corrigan | University of York |
| Clare Dunning | University of Kent |
| Christopher Fewster | University of York |
| José Figueroa O'Farrill | University of Edinburgh |
| Derek Harland | University of Leeds |
| Lotte Hollands | Heriot-Watt University |
| Chris Hull | Imperial College London |
| Christian Korff | University of Glasgow |
| Jens Marklof | University of Bristol |
| Harvey Reall | University of Cambridge |
| Bernd Schroers | Heriot-Watt University |
| James Sparks | University of Oxford |
| Ian Strachan | University of Glasgow |
| Paul Sutcliffe | Durham University |
| Alessandro Torrielli | University of Surrey |
| Dmitri Vassiliev | University College London |
| James Vickers | University of Southampton |

# APPENDIX TWO – AGENDA

**30th March 2016, The Music Room, The Crowne Plaza Hotel, Pendigo Way, NEC Birmingham, B40 1PS**

**10:00 – 10:30 Registration (Tea/Coffee)**

**Introductory Session**

10:30 – 10:35 Welcome

10:35 – 11:00 EPSRC Introduction

11:00 – 11:20 UK Mathematical Physics – Prof James Vickers

**Session One**

11:20 – 11:25 Introduction to the Session

11:25 – 12:25 Research Area Analysis – Quality, Importance, Capacity, Evidence

12:25 – 12:30 Feedback

**12:30- 13:15 Lunch**

**Session Two**

13:15 – 13:20 Introduction to the Session

13:20 – 13:50 Inter/Intra Disciplinary Connections

13:50 – 13:55 Feedback

13:55 – 14:30 Landscape Document Discussion

**14.30 – 14.45 Tea/Coffee**

**Session Three**

14.45 – 14.50 Introduction to the Session

14:50 – 15:50 Future Opportunities

15:50 – 16:00 Feedback

16:00 – 16:30 Discussion and Summary

16:30 End of Workshop

# APPENDIX THREE - OUTPUTS

The raw outputs generated by participants at the workshop are included for information below. Please note that the views expressed are those of the workshop participants and are not necessarily those of EPSRC.

## SWOT Analysis

**Research Area:** Mathematical Physics

**Strengths**

- Landscape document and International Review of Mathematics 2010
- Deloitte report
- High quality of researchers and research
- Mathematical Physics role in creativity- generation of new mathematics
- Mathematical Physics is interdisciplinary and also enabling for many mathematical disciplines
- Mathematical Physics is underpinning- drives large areas of pure mathematics
- Growing interactions with probability, analysis, geometry, and combinatorics.
- Located in maths departments (mostly).
- ERC success in this area- unsure about comparison to the rest of mathematics.
- Leverhulme Knot Grant
- People coming to the UK for Mathematical Physics because of its reputation
- Enriches other courses/training at universities
- UK strength is closeness of Mathematics and Physics (Historical and Cultural). The UK is unique in this.
- Historically famous Mathematical Physicists- Newton, Hawking, Penrose
- Link with popular science (Hawking, Higgs)
- Martin Hairer Fields Medal- related to Mathematical Physics
- Breakthrough Prizes- Hawking, Green
- Unique dialogue with pure maths disciplines
- Much recent international activity e.g. Oberwolfach, Banff, HIS, Hausdorff

**Weaknesses**

- Lack of engagement with more direct applications
- Selling Mathematical Physics-could we do more?
- Timescale of impact- longer than for other areas
- Lack of CDTs mean PhD student funding is reliant on DTP. This means the people

pipeline is insecure.

- Classification of proposals by EPSRC.
- The UK definition of Mathematical Physics is different to the rest of Europe.
- Taxonomy- its name makes it appear a discrete area, however, it is very broad.
- Problems are too hard
- Assuming the future
- Perception by funders
- Few postdocs
- Drop in Early Career Researchers
- Inhomogeneous distribution of higher education

**Opportunities**

- Links with Quantum Information
- Links with non-linear PDE analysis
- Training of PhD students through CDTs
- Case studies of success stories in mathematical physics
- Random matrices and Statistics & Applied Probability
- Repositioning Mathematical Physics as central to Mathematical Sciences **not** at periphery.
- Physics departments currently hiring more experimentalists so many very good quality theoreticians looking for jobs in the UK.
- KCL and Surrey have grown substantial new capacity.
- Problems in nuclear physics
- Statistical Physics applications to finance.
- Applications to network science, complexity, nanotechnology, quantum computing.
- Filter from Pure to Applied
- Exploitation of technique still to be applied.

**Threats**

- Different funding structures in EPSRC and STFC. Can be difficult if working at the interface.
- Hard to get funding for PDRAs on STFC block grant.
- The Fellowship scheme disadvantages academics at the beginning of their careers as the panel rank all career stages on the same list.
- Pressure to repackage research so it fits into STFC or as pure mathematics
- Changes to DTP mean Universities distribute studentships based solely on grants

income. No internal leverage for mathematics.

- Self-censorship in applications, so not applying or repackaging research.
- Increasing reliance on EU funding- what happens if this dries up (e.g. Brexit)
- Hollowing out- losing core capability in the long term?
- Influence on rest of mathematics is not always recognised.
- Emphasis on short term impact
- Losing links with physics
- 'Reduce' label- misunderstanding of broad scope of Mathematical Physics
- Funding for PhD students and Fellows- not funding the future.
- Losing the best researchers to overseas
- Marginalised core 'blue sky' research
- 'Protectionism between areas'
- Unbalanced distribution of PhD funding
- Not attracting overseas researchers because of 'reduce' label.
- CDT concentration of funds/students.

## Interdisciplinary Overlaps Between Mathematical Physics and Other Disciplines

| Research Area: Mathematical Physics | |
|---|---|
| Limited current overlap with some potential for new mathematical developments | Substantial current overlap with high potential for new mathematical developments |
| Cold Atoms & Molecules- Topological insulators, condensed matter, AdS/CFT, integrable systems<br><br>Quantum Optics & Information- Invisibility cloaks, non-linear/integrable systems, advanced materials<br><br>Quantum Components, Devices and Systems- exactly solvable models, high precision measurements and exact data from quantum integrable systems<br><br>Condensed Matter Physics- Spin chains, high $T_c$ superconductors, semiconductors.<br><br>Quantum Technologies- Quantum computing, mathematical characterisation of quantum | Theoretical Astronomy- General relativity, black holes, gravitational waves, model galaxies.<br><br>Theoretical Physics- Solitons, solvable integrable models, statistical mechanics, QFT technologies.<br><br>Particle Physics- LHC, gravitational waves, string theory, skyrmions, Clay Millennium Maths Prize, historical precedents (Dirac, Yang-Mills).<br><br>Particle Cosmology- general relativity, string theory, QFT in curved space-time, black holes, dark energy. |

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|---|---|
| information<br><br>Mathematical Fluid Dynamics- Black hole experiments.<br><br>Chemistry- Minimal surfaces, dimers, symmetry techniques, spectral theory, perturbation theory.<br><br>Nuclear Physics- Through solitons for example. Recent international interdisciplinary conference. | |

Attendees also highlighted that there was some overlap between complexity sciences, for example dynamical systems and spectral theory. However, it was not thought that there was a lot of potential for new mathematics at this interface.

## Intradisciplinary overlaps between Mathematical Physics and the EPSRC Mathematical Sciences Research Areas

| Research Area: Mathematical Physics | |
|---|---|
| Limited current overlap with some potential for new mathematical developments | Substantial current overlap with high potential for new mathematical developments |
| Numerical Analysis- Classical General Relativity, classical field theory.<br><br>Number Theory- Transcendental numbers in QFT, link with amplitude, matrix models, Langlands via string theory.<br><br>Mathematical Biology- knots, tilings, quasicrystals, Weyl group symmetries, swimming algae, viruses, theoretical computer simulations, spin chains, systems biology.<br><br>Dynamical systems- Integratability, entropy.<br><br>Logic- quantum logic, category theory, recent papers in quantum theory, historic links between quantum, logic and philosophy.<br><br>Continuum Mechanics- General relativity, | Algebra- representation theory, integrable systems, non-commutative geometry, cluster algebras, Hopf algebras & quantum groups.<br><br>Combinatorics- Large interface with problems from physics e.g. mirror symmetry, spectral theory from graphs, spin chains, statistical mechanics.<br><br>Geometry & Topology- Knot invariants, four-manifold theory, QFT, moduli spaces, area of UK strength.<br><br>Mathematical Analysis- Spectral theorists often study problems from physics, PDEs (mathematical relativity, QFT in curved spacetime).<br><br>Moonshine theory- LMS Durham Symposium topic |

| | |
|---|---|
| elasticity, shocks, sharing of PDEs as common language.<br><br>Non-linear systems- PDEs, Skyrmions, Waves, quantum optics. | Statistics & Applied Probability- Interaction with Statistical Physics, QFT, stochastic PDEs, random geometry, random matrix theory. |

Attendees also highlighted that there was some overlap between Mathematical Physics and Operational Research. However, it was not thought that there was a lot of potential for new mathematics at this interface.

# APPENDIX FOUR - FEEDBACK

Feedback on the workshop was sourced from participants, with over 60% of attendees responding. The survey requested participants to rate how beneficial they felt each session

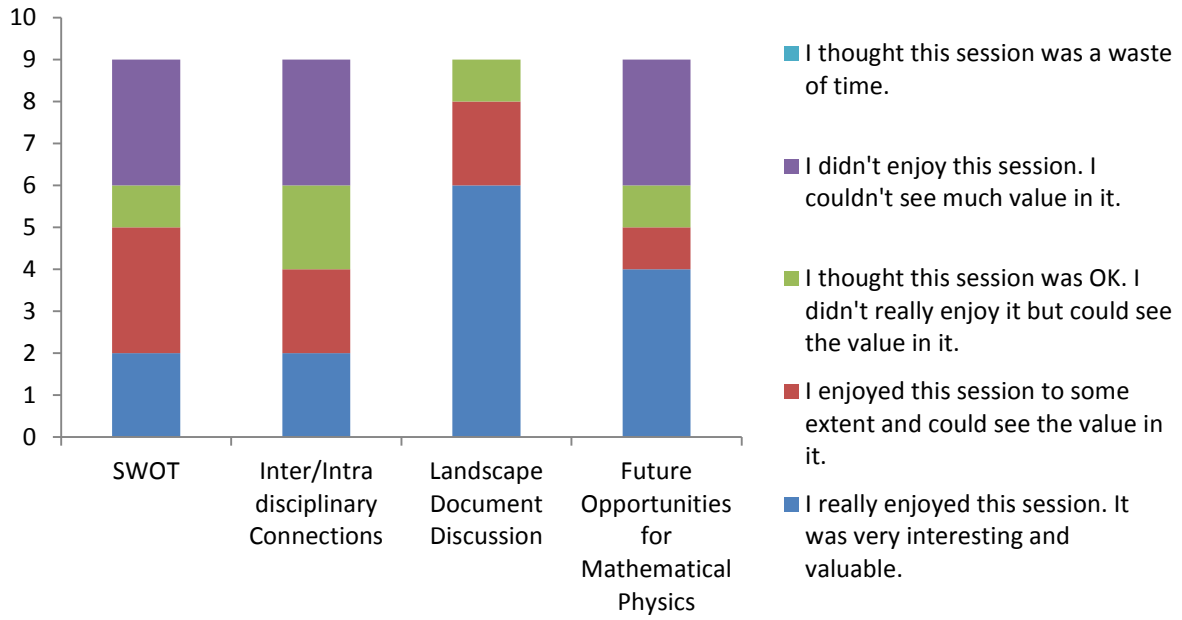


**Figure 1.** Participants feedback on how useful they felt each workshop session was towards the aims of the workshop.

From the participants who responded, 56% said that the information provided in advance was very clear. Full results can be seen in Figure 2.

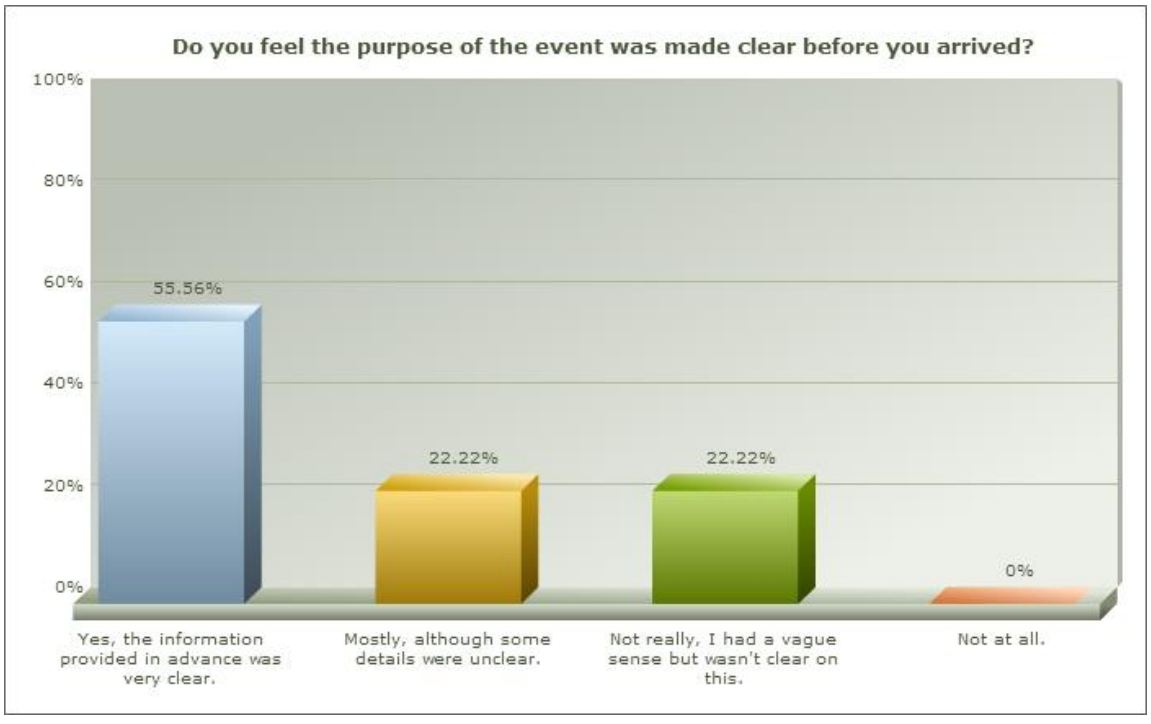


**Figure 2.** Participant feedback on information in advance of the meeting.

From the participants who responded, 78% said they would attend again. Full results can be seen in Figure 3.

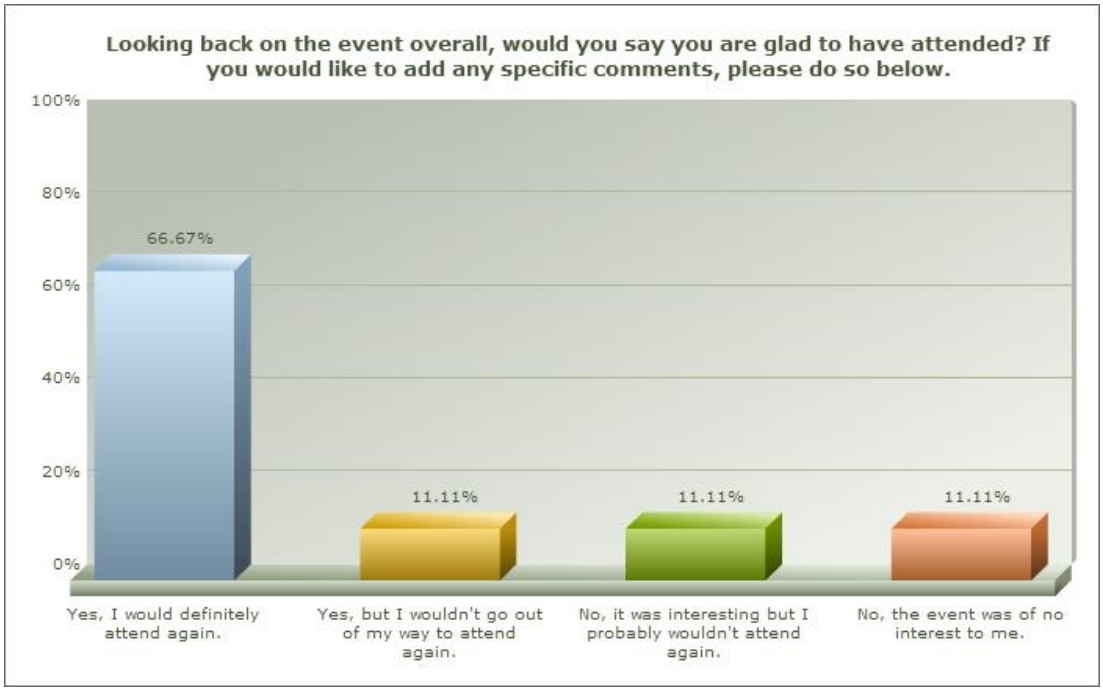


**Figure 3**. Participant feedback on if they would attend the workshop again.