House of Lords Science and Technology Sub-Committee I
Call for Evidence: Higher Education in STEM Subjects
Submission by the Council for the Mathematical Sciences

About the Council for the Mathematical Sciences (CMS)

The CMS (www.cms.ac.uk) was established in 2001 by the Institute of Mathematics and its Applications (IMA), the London Mathematical Society (LMS) and the Royal Statistical Society (RSS). They were joined in 2008 by the Edinburgh Mathematical Society (EMS) and the Operational Research Society (ORS). The CMS provides an authoritative and objective body that exists to develop, influence and respond to UK policy issues that affect the mathematical sciences in higher education and research, and therefore the UK economy and society in general.

- The IMA is the UK's learned and professional society for mathematics and its applications and has around 5,000 members.
- The LMS, founded in 1865, is the UK's learned society for mathematics. The Society has as its purpose the advancement, dissemination and promotion of mathematical knowledge in the UK and worldwide.
- The RSS, founded in 1834, aims to nurture and promote statistics, encouraging statistical knowledge and disseminating good practice in society at large.
- The EMS was founded in 1883 and has around 450 members. Its aims are the promotion and extension of the Mathematical Sciences, particularly in Scotland.
- The ORS is the world's oldest-established learned society catering to the Operational Research profession, with 3,000 members in 53 countries.

SUMMARY:

- **The UK requires a much larger pool of school leavers and university graduates with a strong grounding in mathematical science. While the number of students graduating with good quality first degrees in the mathematical sciences has increased substantially over the past decade, the total remains far from enough to meet the needs of the industrial and education sectors.**
- **The quality of UK undergraduate degrees in the mathematical sciences is high. At the "top" end, quality has been enhanced by the increasing popularity of Integrated Masters degrees. There is a serious risk to the viability of these in the era of high fees.**
- **The 'AAB+' proposals threaten to reduce the numbers taking mathematics A-level.**
- **An atmosphere enriched by research and scholarship is a crucial component of high quality teaching of the mathematical sciences at advanced levels.**
- **The geographical spread of mathematical science departments in UK HE has declined over the past 10 years. This threatens to damage the UK's best use of its mathematical talent base.**
- **Students graduating with UK PhDs in the mathematical sciences are very attractive to the industrial, financial and non-HE educational sectors, but there are very serious problems with the pipeline to careers in UK HE.**
- **Insufficient mathematical science PhDs are being produced to meet demand. The problem of lack of numbers is greatly exacerbated within academia by the inadequacy of the pipeline from PhD to academic positions, a problem which has worsened in 2011 as a direct result of EPSRC actions.**
- **The consensus view in the mathematical sciences community is that, in a time of severe funding restrictions, Taught Course Centres will provide a more sustainable option than Doctoral Training Centres (DTCs), particularly since an emphasis on DTC training will threaten the geographic distribution of PhD provision.**

A. *Graduate supply*

1. *Is the current number of STEM students and graduates (from the UK, EU and overseas) sufficient to meet the needs of industry, the research base, and other sectors not directly connected with STEM?*

- **The UK requires a much larger pool of school leavers and university graduates with a strong grounding in mathematical science. While the number of students graduating with good quality first degrees in the mathematical sciences has increased substantially over the past**

decade, the total remains far from enough to meet the needs of the industrial and education sectors.

1.1 The **size and importance** of mathematical sciences as a discipline is evident at the undergraduate level: with 5475 graduating students in 2007/08, the mathematical sciences undergraduate cohort is nearly the same size as those for chemistry (2965) and physics (2765) combined. The popularity of both “straight” mathematics and “mathematics with” degree courses has been growing. Anecdotal evidence suggests that options such as business and finance have been growing as the “with” option at the cost of more traditional combinations of mathematics with computer science or physics.

1.2 Even with such a large undergraduate cohort there is **a severe lack of qualified mathematics teachers**. Figures in a recent Royal Society report[1] show that only about 2% of primary teachers in England have a specialist mathematical science qualification (fewer than one for every four primary schools). An earlier RS report[2] estimated that there were 21,126 mathematics teachers (including 11,652 who have a mathematical sciences degree, or about 55%) in English secondary schools. DfE data on the shortfall in mathematics teacher recruitment is tabulated in another RS report[3] and graphed in Figure 1 below. The numbers (and gender breakdown) of students accepted on to PGCE/PGDE courses in mathematics is given in Table 1.

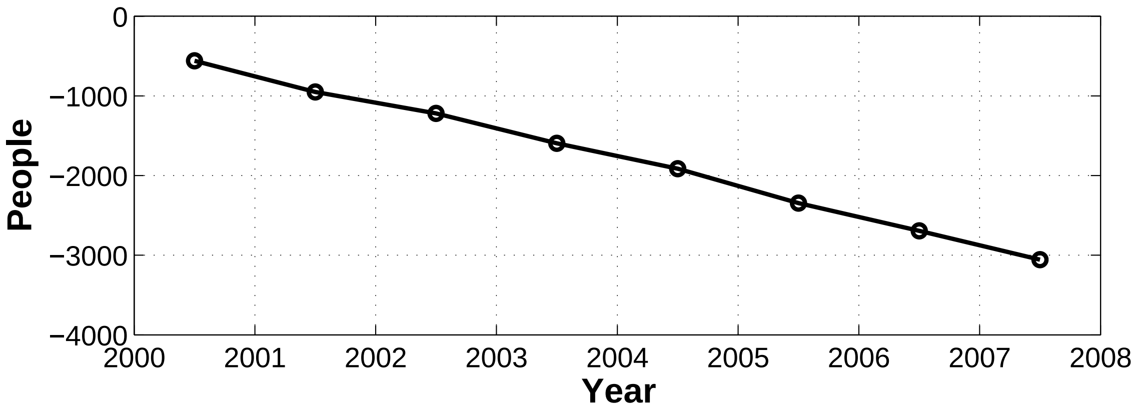

Figure 1: Cumulative shortfall in meeting mathematics recruitment targets, 2000/01 to 2007/08

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total	1162	1311	1502	1858	2059	2066	1835	1645	1599	2068	1881
Male	603	684	841	1020	1173	1107	943	872	846	1085	929
Female	559	627	661	838	886	959	892	773	753	983	952

Table 1: Acceptances to PGCE/PGDE courses in mathematics[4]

1.3 Mathematical sciences **graduates are in high demand in the UK economy**, as shown for example by starting salaries. Table 2 shows the average salary of undergraduates and postgraduates six months after graduation in 2007/08. Mathematical science graduates have excellent career prospects across all sectors. Future growth in the UK will be driven in large part by the knowledge

1 Science and mathematics education, 5-14, The Royal Society, July 2010

2 The UK's science and mathematics teaching workforce, The Royal Society, 2007

3 The Scientific Century: securing our future prosperity, The Royal Society, 2010

4 London Mathematical Society statistics: www.lms.ac.uk/content/statistics-mathematics

economy; this growth would be threatened by an undersupply of well-trained mathematical science graduates.

Subject	First degree	Postgraduate (excl. PGCE)
Biological sciences	£16,500	£22,500
Physical sciences	£19,000	£24,000
Computer science	£21,000	£24,000
Engineering & technology	£23,000	£25,500
Mathematical Sciences	£22,500	£27,000

Table 2: Average salaries of those with first and higher degrees, six months after graduation in 2007/08[5]

1.4 The following (taken from the *International Comparative Performance of the UK Research Base – 2011*[6]) suggest that **the research base is not fully supplied**:

"The UK shows high and increasing activity focus in clinical sciences, health & medical sciences, social sciences, business and humanities. A relative drop is seen in other areas (biological sciences and environmental sciences). The UK has relatively lower activity focus in mathematics, physical sciences and engineering." (p.28).

Possible reasons for this are discussed in the ***Postgraduate supply*** section (**B**).

2. *Is the quality of STEM graduates emerging from higher education sufficiently high, and if not, why not? Do STEM graduates have the right skills for their next career move, be it research, industry or more broadly within the economy?*

- **The quality of UK undergraduate degrees in the mathematical sciences is high. At the "top" end, quality has been enhanced by the increasing popularity of Integrated Masters degrees.**

2.1 Mathematical science degrees are stringently assessed, and evidence from external examiners' reports and the National Student Survey indicates that the quality of teaching is generally very high. Most degree courses include a significant component of project work and HE-STEM[7] has initiatives for incorporating best practice in 'real-life problem-solving' and other transferable skills into university mathematics courses. The introduction of more "generic" content, while clearly enhancing some aspects of the skill set of graduating students, risks diminishing the volume and depth of mathematical knowledge gained. In compensation, a significant number of institutions now offer an Integrated Masters qualification in mathematical sciences in addition to the BSc. These undergraduate masters degrees typically require an extra year of study, but have nevertheless proved increasingly popular over the past decade[8], and students graduating with them are highly valued both by employers and as PhD students.

5 Taken from the table on p 94 of Adrian Smith's report One Step Beyond: Making the most of postgraduate education (March 2010)

6 www.bis.gov.uk/assets/biscore/science/docs/i/11-p123-international-comparative-performance-uk-research-base-2011.pdf

7 www.rsc.org/Education/HESTEM/index.asp

8 For example, registrations for the Mathematics Math/MMast at the University of Cambridge (known as "Part III"), increased by 16% from 2005/6 to 2011/12, from 201 students to 233.

3. *What effect will higher education reforms have on the quality of teaching, the quality of degrees and the supply of STEM courses in higher education institutions?*

- **High undergraduate fees pose a serious risk to the future viability of Integrated Masters degrees.**
- **The 'AAB+' proposals threaten to reduce the numbers taking mathematics A-level.**

3.1 One potential risk is to the **continued viability of valuable Integrated Masters and MSc degree programmes** – if students have incurred a large debt up to BSc level, then it is reasonable to expect that fewer of them will stay for a further year of expensive education.

3.2 The 'AAB+' proposals are likely to reduce the number of university applicants who have taken mathematics A-level. This is because some A-level subjects, including Mathematics and Further Mathematics, are graded more severely than others. There is clear evidence[9] for this. By treating all A-levels as equal the 'AAB+' proposals exacerbate the harm already done by A-level league tables and UCAS tariffs[10]. There is anectdotal evidence that concern for grades (by individuals, schools or HE institutions) leads some students away from mathematics A-level even when their interest and intended area of study would make mathematics the obvious choice.

3.3 However, if the `AAB+' proposals do remain in place, then it is **essential that the list of (protected) SIV subjects continues to include mathematical sciences**. As discussed in **(1)**, the current number of students graduating in the mathematical sciences is already well below the demand.

4. *What effect does "research assessment" have upon the ability to develop new and cross-disciplinary STEM degrees?*

4.1 We have no direct evidence on this question, but we note that there are many existing "Mathematics with" degrees. However, universities are pragmatic and generally structure their departments to map onto mainstream REF disciplines. This can discourage staff appointments at interdisciplinary interfaces and also puts up barriers to novel degree courses.

5. *What is the relationship between teaching and research? Is it necessary for all universities to teach undergraduates and post-graduates and conduct research? What other delivery model should be considered?*

- **An atmosphere enriched by research and scholarship is a crucial component of high quality teaching of the mathematical sciences at advanced levels.**

5.1 The teaching of mathematical science at more advanced levels is informed by current research and students benefit greatly by being taught by someone aware of recent developments. Moreover, recruitment of the best qualified students in good numbers to a mathematical science department is much easier when that department buzzes with the excitement of research being done.

6. *Does the UK have a sufficient geographical spread of higher education institutions offering STEM courses?*

- **The geographical spread of mathematical science departments in UK HE has declined over the past 10 years. This threatens to damage the UK's best use of its mathematical talent base.**

6.1 For example, the number of submissions to the three mathematical sciences Units of Assessment substantially reduced from RAE 2001 to RAE 2008 (from 47 to 37 in pure mathematics, from 58 to 45

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9 www.score-education.org/policy/qualifications-and-assessment/grading-severity

10 The high percentage of A and A* grades achieved by Mathematics and Further mathematics A level candidates does not reflect more generous marking, as "linked pair" studies by each Awarding Body routinely shows.

for applied mathematics and 46 to 30 for statistics and operational research). The UCAS database included single honours first degrees in statistics from only 10 UK universities for 2011 entry. The Steele Report[11] has highlighted the problem of lack of provision in certain areas caused by the closure of departments. Two of the main findings of the EPSRC's International Review of Mathematical Sciences[12] are that (with our emphasis): "*Overall, mathematical sciences research in the UK is* ***excellent on an international scale"****,* and *"the high quality of UK mathematical sciences research* ***depends critically on the diverse and distributed research community"****,* where `diverse' includes research area, group size and institution size, and `distributed' refers to geographical location.

6.2 There are risks in excessive concentration of research funding, as this may threaten the current geographical spread of institutions offering mathematical sciences degrees. In the era of Full Economic Costing, research-intensive HE institutions are likely to focus investment in fields where substantial grant income is more likely. At the same time students are more likely to choose to study close to home when the cost of a degree is rising fast, so that **there is a severe risk of reducing the number of highly-skilled mathematical science graduates** produced in the UK.

7. *What is being done and what ought to be done to increase the diversity of STEM graduates in terms of gender, ethnic origin and socio-economic background?*

7.1 Most universities select on A-level results, or their equivalent, and attaining the right qualifications remains the highest hurdle for those from low-participation backgrounds, something which clearly affects the mathematical sciences as well as other subjects. Mathematical sciences have a slightly lower proportion of students from low-participation neighbourhoods (15.2%) than the overall figure (16.4%) (HESA data). Conversely, HESA data show that in 2009/10 21.6% of students in the mathematical sciences were from black and minority ethnic backgrounds, compared with 18.3% for the student population overall. While this gives no grounds for complacency, it is not evidence that the mathematical sciences have a greater than average need for action. The HEFCE-funded More Maths Grads project[13] which ran from 2007 to 2010 was focused on increasing the number of students studying mathematics, in particular encouraging participation from groups of learners who have not traditionally been well represented in higher education.

7.2 At about 40%, **the proportion of female mathematical science undergraduates is relatively high** compared to other STEM subjects[14]. But there is severe **attrition on the path through to academic positions**: 32% of mathematical science postgraduates are female, compared with 20% of the holders of postdoctoral posts, 22% of lecturers and a tiny 4% of professors. Reliable research on the reasons for this decline does not seem to be available, but it seems reasonable to conjecture that the problems with the academic career pipeline discussed in **(9)** affect female mathematical scientists most severely.

Post-graduate supply

8. *Is the current training of PhD students sensitive to the range of careers they subsequently undertake?*

- **Students graduating with UK PhDs in the mathematical sciences are very attractive to the industrial, financial and non-HE educational sectors, but there are very serious problems with the pipeline to careers in UK HE.**

We discuss the first part of the above answer here, and the second part in **(9)**.

8.1 As shown in Table 2 above, mathematical sciences PhD graduates attract the highest starting salaries of all PhD graduates. The value placed by employers outside academia on the doctorate can

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11 www.cms.ac.uk/reports/2007/steele_report.pdf

12 Report available from www.epsrc.ac.uk

13 www.moremathsgrads.org.uk/home.cfm

14 www.theukrc.org/files/useruploads/files/final_sept_15th_15.42_ukrc_statistics_guide_2010.pdf

be seen from the fact that in 2006, six months after graduation, the average salary of someone with a mathematical sciences first degree was £22.5k, whereas the average for someone with a PhD in mathematical science was £27k. According to the annual HESA surveys for 2004-2008, 42% of doctoral graduates in mathematical sciences find work in the education sector, 34% in finance, business and IT, and 18% in other sectors.

9. *Are we currently supporting the right number of PhD studentships to maintain the research base and are they of sufficient quality?*

- **Insufficient mathematical science PhDs are being produced to meet demand. The problem of lack of numbers is greatly exacerbated within academia by the inadequacy of the pipeline from PhD to academic positions, a problem which has worsened in 2011 as a direct result of EPSRC actions.**

We split **(9)** into three questions:

(i) *How many appointments per year are needed to maintain the UK academic mathematical sciences research base in steady state?*

9.1 According to HEFCE, 1933 FTEs were returned in the mathematical sciences in RAE 2008. Assuming a 40 year career, this would mean 50 new academic staff each year. In fact, however, the data collected in Table 3 below shows that, over the past decade there have been substantially more than this number of new appointments, averaging at least 70 per year. This follows the retirals of many academics appointed in the expansion of the1960s, and some expansion with the increase in UG numbers.

(ii) *Is UK output of PhDs supplying the requisite numbers?*

9.2 Based on the first destination data gathered for the 2004-2008 HESA surveys, we estimate that about 10% of mathematical sciences PhDs become lecturers in UK HE. Since demand for UK PhDs in the mathematical sciences greatly exceeds supply (see **(1)**), it would be damaging for this percentage to increase, so that at least 500 UK mathematical sciences PhDs are needed annually to maintain the academic research base from within.[15] We estimate that the UK in fact produces about 400 PhDs in the mathematical sciences annually. However, as Table 3 shows, **a considerable majority of the new appointments over the past decade have not come from those educated in the UK.** The UK is indeed very fortunate to have been able to recruit such large numbers of top quality mathematical scientists from around the world, but there are obvious risks arising from this development: there are dangers of instability; and there is a serious risk that UK students will come to believe that a career in mathematical sciences research is not a viable option for someone educated in the UK.

Appointed up to and including 2000	Trained in the UK	348
	Trained overseas	129
Appointed after 2000	Trained in the UK	371
	Trained overseas	460

Table 3: Background of UK HE mathematical sciences staff in post in November 2011[16]

(iii) *What are the reasons for the shortfall in (ii)?*

15 One might argue that overseas PhDs should correct any shortfall. But if the system works well, any supply from overseas should be balanced by UK PhDs going to academic posts abroad.

16 From an LMS survey of UK mathematical sciences departments carried out in November 2011, for this report, 39 departments supplied data, out of 47 approached.

9.3 One reason is already clear from **(1)** and **(9.2):** the **UK is producing insufficient PhDs in the mathematical sciences** to meet the current demand. The obstacle here is a scarcity of funded scholarships – demand from prospective PhD students is vibrant, but many good students have to be turned away due to lack of financial support.

9.4 A second reason concerns the **pipeline from PhD to academic position.** The academic jobs market in the mathematical sciences is truly international, and few people are appointed to a permanent UK academic position without a substantial research track record. Given the short duration of the UK PhD (normally 3.5 funded years after first degree[17]), UK PhD graduates typically need one or more postdoctoral positions in order to successfully apply for a permanent academic post. A good pipeline from UK PhD to academic career thus **needs around 100 postdoctoral positions per year for newly graduating PhDs in the mathematical sciences.** Unfortunately this is far from the case and we regard this as a **very serious threat to the research base.** In recent years there have typically been (in addition to a number of RC-funded posts as Research assistant) about 10 EPSRC-funded 3-year Postdoctoral Fellowships per year in the mathematical sciences. These have been discontinued by EPSRC in 2011, except in Statistics and Applied Probability, a decision which has caused alarm and outrage in the community, and has prompted letters to the Prime Minister from a group of prominent mathematical scientists and from 300 young researchers.[18] Thus**, a pipeline which was already badly malfunctioning has been seriously damaged by EPSRC decisions.**

10. *What impact have Doctoral Training Centres had on the quality and number of PhD students? Are there alternative delivery models?*

- **The consensus view in the mathematical sciences community is that, in a time of severe funding restrictions, Taught Course Centres will provide a more sustainable option than Doctoral Training Centres (DTCs), particularly since an emphasis on DTC training will threaten the geographic distribution of PhD provision.**

10.1 It is clear that the introduction of the **Doctoral Training Centres (DTCs) have reduced the overall numbers of STEM PhD students funded by EPSRC**, because of their much higher *per capita* costs. Thus it costs around £75k in total to fund a 4-year PhD from the Doctoral Training Grant, whereas the typical cost per 4-year PhD funded by a DTC is close to £100k.

10.2 Two noteworthy features of research in the mathematical sciences are: (a) there is no need to concentrate students to make use of expensive facilities; and (b) the key enabling resource is the availability of really talented supervisors, who are rather widely spread across institutions. Bearing these features in mind, the **EPSRC-funded Taught Course Centre model** is a cost-effective way to provide core training to PhD students while capturing most of the benefits of DTCs, but without the severe constraints, expenses and damaging effects[19] of co-location. Several successful methods have been devised to work within these constraints.[20] In the first model, there are several networks of universities (one in Scotland, MAGIC in Northern England and one based in Oxford) with videolinked lecture theatres by which the localised expertise can be distributed across students in many institutions; these are supplemented by an annual conference in which students meet in person. APTS is a longstanding organisation for training postgraduates in Statistics, training annual cohorts of the order of 80 first-year Statistics PhD students by means of four residential weeks per year, and NATCOR makes a similar arrangement in Operational Research. Another group exploits the density of institutions in London to bring groups of students together.

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[17] The typical length is two years more in the US and in much of Europe.

[18] EPSRC's revised Fellowship schemes introduced in November 2011 continue these restrictions at the postdoctoral level.

[19] Given restricted funding, concentrating large numbers of students in one place implies few or no students elsewhere.

[20] www.epsrc.ac.uk/SiteCollectionDocuments/Publications/reports/EPSRCReviewOfTCCs.pdf

11. *Should state funding be used to promote masters degrees and is the balance right between the number of masters degree students and PhD students?*

- **State funding should be used to support masters degrees in areas of key national need, such as in the mathematical sciences.**

11.1 At present the main "state funding" at masters level in mathematical sciences is for Integrated Masters degrees, with some RCUK funding for a few courses in areas of statistics and operational research. In view of the lack of first degrees in statistics and operations research, entry to professional and research posts in these disciplines now typically requires prior study at masters level. There is thus a pressing requirement for state support for masters degrees in such areas of particular national need. It is also to be regretted that a number of excellent masters courses in applied and computational mathematics no longer receive such support.

12. *What impact will higher education reforms have on the willingness of graduates to pursue a research career?*

- **The path from first degree through to PhD in the mathematical sciences currently depends heavily on Integrated Masters degrees. As discussed above ((1) and (3)), this pathway is likely to be at risk in the face of high increases in fees.**

15 December 2011