Opinion Forum

Campaign for Science & Engineering in the UK

The views of members and supporters of CaSE Number 7 May 2007

Secondary Science Education

Summary of findings and recommendations

There is a crisis in secondary science and mathematics education in maintained schools, with a shortage of physics, chemistry, and mathematics teachers and low student interest. CaSE recommends the following steps.

- The Government must set subject-specific goals for chemistry, physics and mathematics recruits to teacher training courses.

- Headteachers should be encouraged to make greater use of existing flexibilities in remuneration where they have difficulty recruiting teachers. They could be motivated to do so by including whether a school has specialist chemistry, physics and mathematics teachers in School Attainment Tables.

- Improving teacher retention would be an efficient way to increase numbers and might be achieved by recruiting more support staff and technicians, who should themselves experience improved remuneration and career prospects.

- Ring-fenced funding must be provided for the retraining of teachers into shortage subjects and for support staff and assistants to specialise in these subjects. Teaching cover and incentives to participate should be included.

- To increase uptake of science A levels, the Government needs to recognise that A levels differ in difficulty and increase the academic requirements of the less challenging ones. Careers advice in schools must be improved as a matter of urgency. The inequalities in provision and quality of science and mathematics education across types of school, gender and ethnic groups must be reduced.

- Practical science teaching must be increased and improved. A sustained increase in recruitment of technicians and support staff should help with large class sizes, workload and behavioural problems. Schools should be allowed to carry over funds for large purchases and there must be an immediate and considerable financial investment to get laboratories up to standard. A central website should support practical work, including advising on Health and Safety Issues and coordinating a national scheme to share donated equipment.

- The growth of science enrichment schemes is laudable but has little impact on the majority of schools and pupils, particularly those without science specialist teachers.

- The declining uptake of physics and chemistry observed in the UK seems to reflect a societal shift, and cross-cultural data suggest a certain inevitability to this. However, an apparently terminal decline in interest in further mathematics in the UK has been rapidly reversed following proactive intervention. There is no reason to assume that interest in chemistry and physics would not similarly increase following appropriate interventions. We must to work to improve children's perceptions of the benefits of science and technology and of those working in the area.

This report is based on discussions with a range of representatives from companies, universities, government departments, trade organisations, learned societies, teaching and others.

The document stemmed from a meeting with members of CaSE's Advisory Council and other interested parties at the House of Lords in January 2007, which was followed up with correspondence and conversations with a wider range of individuals.

The findings are broadly representative of the participants' views, but the specific opinions are the responsibility of CaSE.

This document is one of a series of Opinion Forums that present the views of CaSE's members, contacts and supporters about current issues in science and engineering policy.

Detailed background information and references for this document can be found on the CaSE website:
www.sciencecampaign.org.uk/documents/archive.htm

Teaching science...

Everyone needs to have a strong science education to enable them to understand and make informed choices about the myriad of ways in which science affects our modern lives, and to appreciate the scientific achievements in our cultural heritage. Some students will pursue this education to a higher level, for a scientific or technological career or to bring these skills to other areas.

There has been a massive amount of change in secondary science teaching, with the introduction of new syllabuses, science enrichment opportunities, and initiatives to increase teacher recruitment. All this change has occurred alongside advancing scientific knowledge and more general initiatives such as specialist schools and city academies. It is easy to see why some teachers and students are overwhelmed. While we urge the Government to pursue our proposals, it is necessary to appreciate that even positive change can be negative in impact if too much is pursued too readily, and that all change should be evidence-based.

...for our future

"...we need to ensure our education system can give young people the skills they need. This means modern laboratories where pupils can enjoy the fun, hands-on aspects of science under the tuition of teachers with the specialist knowledge to give them the depth of knowledge and inspiration they need."

John Cridland, The Confederation of British Industry (CBI) Deputy Director-General, March 2007.

The CBI estimates that the number of science, engineering and technology graduates needs to double, from 45,000 to 97,000 each year to fulfil employer demand in our increasingly knowledge-based economy. If the UK education system is unable to produce these scientists, we will become reliant on overseas experts or see the science-based economies move overseas, given that the most important factor in determining where multinationals invest in research and development is access to talent.

There is a Massive Shortage of Specialist Teachers in Maintained Schools

■ The shortage of specialist teachers (with a degree or additional teacher training in the subject) is not evenly distributed: 44% of science teachers are biologists, 25% are chemists, and 19% are physicists. Only 76% of mathematics teachers are specialists.

■ The situation is most critical in physics. Half of all schools for 11- to 16-year-olds have one in four or fewer specialist physics teachers and a quarter of all schools have no specialist physics teachers. A third of GCSE physics teachers do not even have a physics A-level. The situation may further deteriorate as 39% of teachers leaving in 2004 were physicists compared with 33% of those entering teaching, and physics teachers are generally older than those of other subjects.

■ The lowest-attaining schools and those in areas of socio-economic deprivation are more likely to lack specialist teachers and low ability groups are more likely to be taught by non-specialist teachers.

■ The quality of science teachers is also a concern. Overall, 56% of postgraduate trainees with UK degrees had a classification of at least 2:1 as compared with 47% of science teachers and 39% of mathematics teachers.

Children need to be taught by specialist teachers. Teachers' qualifications predict teaching quality and are the second greatest predictor of performance in physics after pupil ability. Poor teaching decreases uptake and grades, and this, in turn, produces a shortage of graduates available to become teachers.

Government Targets in Teaching

Step up recruitment, retraining and retention of specialist teachers, so that by 2014:
- 25% of science teachers have a physics specialism (currently 19%)
- 31% of science teachers have a chemistry specialism (currently 25%)
- 95% of mathematics lessons to be delivered by a specialist (currently 88%).

Steps taken to meet these targets include:
- Financial incentives to recruit physics and chemistry teachers via Employment Based Routes
- Develop a Continuing Professional Development (CPD) programme to give existing science teachers a physics or chemistry specialism.

Increasing Teacher Recruitment

Low pay is the biggest deterrent for undergraduates considering teaching, even after the introduction of 'golden hellos' (£5000 for new recruits in specialist subjects). Consistent with this, shortages are more pronounced in some geographic areas and disciplines with higher external salaries. Pupil behaviour and the likelihood of teaching non-specialist subjects in combined science lessons are other deterrents.

Around 3000 science and 2000 mathematics recruits entered teacher training in 2006/7. The science recruits included 977 (26%) biologists, 568 (15%) chemists and 383 (10%) physicists. It is hard to see how such a small proportion of physics and chemistry specialists is going to significantly improve the situation.

The Government MUST set subject-specific goals for recruiting chemistry, physics and mathematics teachers. CaSE believes that this simple reform will greatly improve the situation.

Unfortunately, the Government has significantly over-stated the number of new hires of science teachers, confusing this with the number of trainee recruits in science, engineering, mathematics and technology (which includes business studies, textiles and graphics):

"There is already some progress. Science teacher vacancies are already falling. 7,500 new science teachers were hired in 2005 - 70% more than 1999/2000." Prime Minister Tony Blair
Our Nation's Future - Science, 3 November 2006

This misunderstanding may have grave consequences if government ministers believe the situation to be better than it is.

A controversial proposal to increase recruitment would be to increase the pay of teachers in specialist subjects. Such a solution for all 44,000 secondary science and mathematics teachers would be expensive and inefficient.

Headteachers must be encouraged to make greater use of existing flexibilities in remuneration where they have difficulty recruiting subject teachers.

These include starting teachers higher up the pay scale, doubling pay increments for excellent performance, and recruitment and retention incentives. Headteachers need to be assured of the appropriateness of these measures and the clarity with which they can be advertised.

The most effective way to motivate headteachers to use these flexibilities may be for School Attainment Tables to include whether a school has specialist chemistry, physics and mathematics teachers.

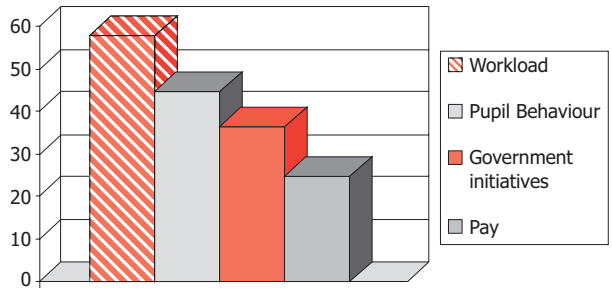
Many recruits pre-train to develop a specialism and new diplomas are being introduced to enable teachers to specialise in chemistry and physics later in their careers.

Schools must be provided with additional funding for diploma fees and cover staff and teachers should be offered financial incentives to retrain.
The School Teachers' Review Body recommends an incentive comparable to the 'golden hellos'.

Specialist Support Staff & Technicians & Retention of Teachers

Shockingly, only about three in every five new teachers are still working in maintained schools after five years. Factors most frequently cited for leaving the profession are workload (58%), pupil behaviour (45%), government initiatives (37%), and pay (25%) (see Figure 1).

Figure 1. Factors cited by teachers for leaving



Source: Teachers Leaving, NUT, 2001

A recent survey of mainstream schools found that mathematics and science teachers were dissatisfied with workload, pupil behaviour, and lack of support staff. Pay was not a big factor. In contrast, two thirds of science and mathematics technicians and support staff were satisfied with their work but only 10-25% of them were satisfied with their pay; they were also dissatisfied with the lack of career progression, appreciation and support. Despite this, another survey found that technicians were consistently cited as positively affecting pupil behaviour and teacher workload, job satisfaction, and stress levels.

The most effective way to improve retention of science and mathematics teachers would be to provide more support staff who themselves experience better pay and career prospects.

CaSE is pleased to note increasing numbers of technicians and strongly supports the subject-specific training of assistants - it is essential that their training is appropriately funded, with provision for teaching cover.

Continuing Professional Development (CPD)

All science teachers should have access to CPD, but only half of all secondary science teachers have taken CPD in the past 5 years, possibly because of poor access to courses away from London, and a reluctance or inability of schools to cover both the costs of the courses and supply teachers. Given that access improves, it may be appropriate to link CPD to career progression. CPD may also improve teacher retention.

GCSE & A level Performance

All children are required to study science up to about 16 years of age (i.e., Key Stage 4 or Year 11). Table 1 details performance in 2005. What is striking is the small minority of children taking separate biology, chemistry, and physics (7-8%), although these students perform very well, at least 90% achieving A*-C grades. The majority of children take the three sciences combined as double science (two GCSEs) and 57% of them achieve A*-C grades. Just 11% of children took single science GCSE and they would have probably struggled with more.

Table 1. 2005 GCSE science and mathematics results

	Thousands of pupils (percentage of total)	Grade A*-C	Grade A*-G
Mathematics	605.3 (98)	55	97
Any Science	583.1 (95)	55	97
Single Award Science	65.5 (11)	20	92
Double Award	450.9 (73)	57	98
Physics	45.4 (7.4)	91	100
Chemistry	45.9 (7.4)	91	100
Biological Sciences	48.3 (7.8)	90	99
Other Sciences	7.6 (1.2)	52	95

Source: DfES

Performance varies greatly with type of school. In 2002, only 19% of maintained schools offered separate sciences and those studying the sciences were less likely to gain an A grade than those in the independent sector. Independent schools account for a third of triple science entries and gain over 50% of the A* grades, similarly, they account for around 7% of mathematics entries, but over 30% of A* grades. The inequality of performance is illustrated in Figure 2(a), showing that the percentage of pupils gaining at least one science GCSE grade C is 47% for mainstream schools, 59% for science specialist schools, 95% for grammar schools and 86% for independent.

In Year 12, a number of AS levels are typically taken followed by fewer A levels in Year 13. Table 2 illustrates the pattern of A level entries over the last decade. Numbers taking physics have declined, while numbers taking biology and chemistry fluctuate, but not too dramatically. Mathematics had significantly declined but recently started to recover. The pattern of preference has changed massively over the last 20 years, given than in 1984 physics was the most popular science A level, and biology the least.

Table 2. A level entries for science and mathematics in English schools and colleges over the last decade

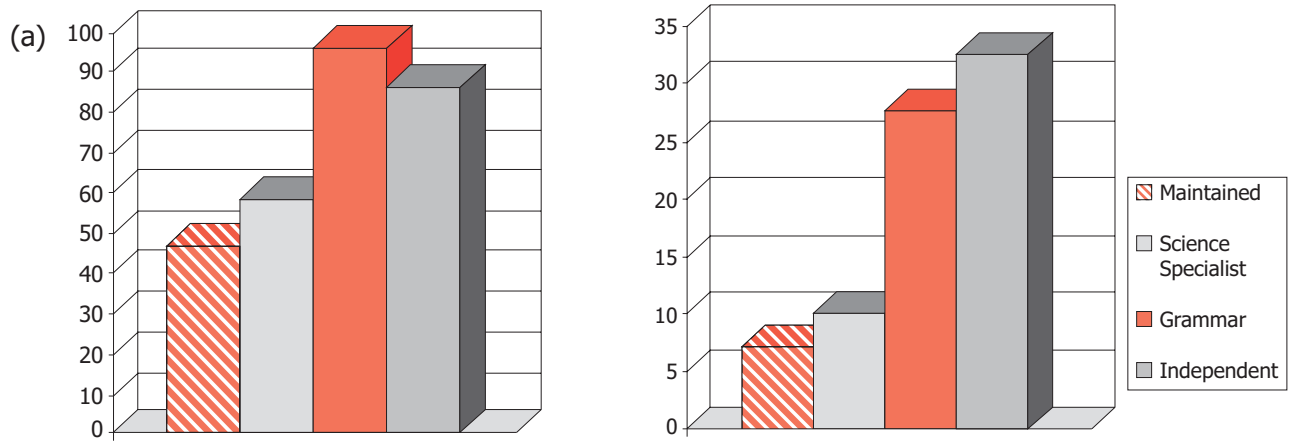
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Biology	47,807	48,897	47,192	46,190	44,592	45,407	43,902	44,235	45,664	46,624
Chemistry	36,613	37,103	35,831	35,290	33,871	32,324	31,065	32,130	33,164	34,534
Physics	28,903	29,672	29,552	28,191	28,031	27,860	26,278	24,606	24,094	23,657
Other science	4,301	4,325	4,124	3,834	3,587	3,740	4,029	3,773	3,779	3,599
Mathematics	56,050	56,589	56,100	53,674	54,157	44,156	44,453	46,017	46,037	49,805
Further mathematics	4,999	5,211	5,145	5,015	5,063	4,498	4,730	5,111	5,192	6,516

Source: DfES

As with GCSEs, science A levels are greatly affected by schooling. Just one in ten students take at least one science A level in mainstream or science specialist schools, as compared with about one in three at grammar and independent schools (see Figure 2b).

The inequity in science and mathematics education across different types of schools is indefensible, especially given the long term benefits of this education to individuals. The provision and quality of science and mathematics education in maintained schools must be improved.

Figure 2. Performance shown by place of study as (a) Percentage of students gaining A*-C in any science GCSE and (b) Number of 15 year olds taking at least 1 science A level



Source: House of Lords Science and Technology Committee, 10th Report of Session, 2005-06, Science Teaching in Schools. Evidence from the DfES

Why are science A level numbers dropping?

■ Lack of GCSEs and teachers
The majority of children now take two science GCSEs. In the past, this was good preparation for these subjects at A level. Now, however, children are encouraged to take triple science if they want to do A levels, and they would be well-advised to do so. For instance, pupils who take triple science are 76% more likely to get an A or B grade in A level chemistry compared to those who take double science. Furthermore, if students have particular difficulty in one subject area of double science, it will affect their whole grade and may limit their access to a science A level they excel in. In schools with a shortage of specialist teachers, poor quality GCSE teaching may have diminished preparedness and enthusiasm for A levels or they just may not be offered.

■ Competition from other A levels
There are now 70 subjects offered at A level many of which are more attractive to students who often perceive sciences as relatively difficult, boring and unfashionable. The excitement and enjoyment of science lessons may well have diminished with the decline in practical lessons. Students tend to choose subjects based on enjoyment, anticipated grades, and career opportunities.

Students accrue points for their A level grades and universities typically offer places with a certain point requirement, sometimes specifying certain subjects and grades. All A levels are rated equal in terms of points despite evidence that some (e.g., Sociology and Business Studies) are easier.
Students may choose easier A levels to get more points, and schools and colleges may encourage them to do so because of their own performance in league tables. Some universities now require applicants to take traditional subjects.

CaSE calls upon the Government to recognise the inequality among A levels and to increase the academic requirements of the less challenging ones. On no account should the more challenging subjects be "dumbed down".

■ Dropping difficult subjects after AS levels
Students who might have previously taken science and mathematics to A level may be discouraged by their relative difficulty and discontinue after a year of study having gained an AS level. Standardising the difficulty among subjects and providing better information on the advantages of continuing study may improve the situation.

■ Inadequate careers advice
Only 10% of careers advisors have a background in science, and 90% said that they were not confident advising on science careers. Accordingly, students have been inappropriately advised away from the sciences (see recent CaSE Opinion Forum). The Government has recognised the problem and pledged funds for a Careers for Science website in July 2004, but has only just delivered them.

CaSE calls upon the Government to improve the quality of careers advice in schools immediately.

■ Lack of pull through from Higher Education
The market-driven approach of UK universities, combined with inadequate funding for laboratory-based sciences, has led to the closure of about 50 physics and chemistry departments over the last decade. In an Opinion Forum on Higher Education, CaSE argues that it is essential to provide adequate funding and financial incentives for students (such as reduced course fees and student debts). As more students plan to take these subjects at university, A level uptake should correspondingly increase.

Government Targets in GCSE & A Levels

- Continually improve the science performance of pupils at the end of Key Stage 3 and GCSE
- Increase the number of students taking science A levels so that by 2014 35,000 take A level physics 37,000 take chemistry A level and 56,000 take mathematics A level

Steps taken to meet these targets include:

- From 2007, the number of pupils achieving a C or above in at least two science GCSEs will be included in the School Accountability Framework
- By September 2008, all pupils achieving at least level 6 at Key Stage 3 will be entitled to study triple science GCSE, although not necessarily in their own school

We welcome these measures but believe that children should always have been entitled to study triple science. We are concerned about the practical arrangements for children studying at other schools and the increasing provision of "entitlements" with strings attached. An entitlement to take time out of the school day to travel to a different school to be taught triple science by a non-specialist teacher is not likely to be very beneficial.

Science Practical Classes

The practical component of science courses teaches fundamental skills and is highly motivating. Sadly, there is much evidence from surveys performed by CaSE and other sources that teachers are reducing practical work for a number of reasons:

- Class sizes are too large and behavioural problems are particularly pronounced and dangerous in practical lessons
- Lack of assistants and preparation time
- Poor understanding of Health and Safety Issues
- Inadequate funding for large items of equipment
- Unsafe and uninspiring facilities

It is straightforward to tackle most of these points. Although it would be desirable, requiring schools to reduce the number of students in practical classes may produce scheduling problems and lead to a further reduction in the number of classes. **Instead, we support a sustained increase in recruitment of science technicians and support staff (well paid and with an improved career structure) to help ameliorate the large class sizes and ease the burdens on class teachers.**

Teachers need to be provided with accurate Health and Safety information and appropriate support. The Consortium of Local Education Authorities for the Provision of Science Services (CLEAPPS) reported that most calls to a member helpline concerned practical work, and about a sixth simply asked whether an activity was allowed or not.

Regarding equipment and facilities, the Royal Society of Chemistry found that 66% of school laboratories were rated as basic (uninspiring) including 25% that were unsafe or unsatisfactory, and it estimated that £1.38 billion would be required to upgrade all to a good standard. The Building Schools for the Future programme aims to replace or refurbish all secondary schools by 2020 but funding needs to be earmarked for laboratories and it has been announced that the £200 million pledged in the run-up to 2005 Election will not now be delivered. Depressingly, new builds and refurbishments are reportedly of poor quality and occurred without consulting expert groups. A CaSE survey found that good laboratory facilities enhanced recruitment and retention of teachers.

A considerable financial investment is essential to get laboratories up to standard. Schools should also be allowed to carry over funds to make large purchases. In addition, a central website should be formed to support practical work, including advising on Health and Safety Issues and coordinating a national scheme to share equipment donated from universities and other sources.

"Science is a practical subject, so if you are not doing that, you are not doing science."

Dr Peter Cotgreave, Director of CaSE
23rd March, 2007, Times Educational Supplement.

Enriching Science Teaching

There has been a massive increase in initiatives to enrich secondary science teaching. CaSE applauds the growth and variety of these schemes and looks forward to their improved coordination through the Regional STEM Support Centres. However, academics must receive credit for their contributions and schemes need to be more fully evaluated.

CaSE is concerned, however, that the Government frequently refers to these schemes when asked what it is doing to improve the uptake of sciences. While they are undoubtedly beneficial for those involved, most depend on the interest and enthusiasm of teachers and some of the schemes are not intended for all pupils. Most will have little impact on the majority of schools or the majority of pupils, particularly those without specialist science teachers.

The Evolving Science Curriculum

Science GCSEs have just been updated with the 21st Century Science courses launched in 2006. An introductory course, *Science*, provides scientific literacy to all, covering topics like correlation and causality, data limitations, risk and decision making. *Applied Science* provides more vocational skills and *Additional Science* is good preparation for A levels. Students learn through role play and debate and also consider moral and ethical issues.

Unfortunately, the courses have been rolled out before being fully evaluated, with new A levels due to start in 2008. It is ironic indeed that courses intended to teach the ability to evaluate evidence have been introduced before their own impact has been properly assessed. There is a risk that the courses are not sufficiently intellectually rigorous and that we will create a population keen to engage in lively debate of scientific issues but ill-equipped to do so.

In another development, from 2008, new diplomas are being introduced and include work experience, to provide "real world" knowledge and skills for students of all abilities, aged 14-19. CaSE is concerned that diplomas may divide the education system, pigeonholing some lower-ability students into a particular career path too young. We support a broader system which allows students to keep options open for longer.

Finally, the scientific community must continue to attend to the expanding Academies programme in which sponsors are given considerable powers over the curriculum, after Gateshead Academy included creationism in biology lessons.

Socio-economic Status, Gender, and Ethnic Influences on Science A levels

Socio-economic status probably has most impact through access to schooling although there may also be aspirational and motivational factors.

In relation to gender, girls are under-represented in physics and mathematics and over-represented in biology. It has been argued that girls are affected by lack of role models and stereotyped examples, are less inclined to take harder subjects, and are particularly affected by teaching quality. In addition, there is evidence that, compared to boys, science teachers devote less time to girls, have lower expectations of them, and give them less credit for the same work. While boys are often criticised about their behaviour, girls are criticised about their work.

Increased uptake of physics and mathematics A levels by girls would improve the gender balance and increase overall rates. CaSE supports any measures targeted at this problem, including modernising the curriculum and improving careers advice. In addition, it is important to develop ways to monitor and improve student-teacher interactions, possibly as part of CPD.

There is a complex relationship between ethnic background and science. At A and degree level, black African, Indian, and Chinese students are over-represented, compared to white students, whereas black Caribbean and Bangladeshi students are under-represented. Chemistry is favoured by ethnic minorities, possibly because of the bias towards medicine shown by most ethnic minorities. Overall, most ethnic minority students tend to favour computing and technology courses.

In an attempt to improve the uptake of science among certain ethnic groups, the Government Science in Society Program enables schools with a high proportion of Afro-Caribbean, Bangladeshi, or Pakistani pupils to bid for funding for extra-curricular science learning activities.

CaSE applauds such initiatives but believes that the money may be better spent making sure that these schools have specialist science teachers. Improved careers advice should broaden the careers that different ethnic minorities perceive as appropriate for themselves.

Cross-Cultural Influences

Falling student interest in the "harder" sciences and technology is not unique to the UK. A multinational project reported that most 15-year-olds believed that science and technology was important for society, however, they were less sure that the benefits out-weighed any harmful effects. There is a fascinating effect of the level of development of countries (as measured by income, education and health), with less developed countries being more positive. This effect was even more pronounced when children responded about their plans: boys and to a lesser extent girls in developing countries said that they would like to work in science or technology. In contrast, most boys and especially girls in more developed countries said that they would not like to be scientists. The gender difference is more pronounced in technology: most boys in developed countries were neutral on working in technology whereas girls were decidedly negative.

These cross-cultural data suggest that more developed societies may have to work to improve the public (and especially children's) perception of the benefits of science and technology and of those working in the area.

Further Mathematics Numbers are Rising: A Case Study for Success

The number of further mathematics A level students fell from around 15,000 in the early 1980s to 5,000 by the late 1990s. Some schools and colleges stopped offering the subject because of small classes and staff shortages, leading universities to drop it as an entry requirement, further reducing demand. The decline of further mathematics was particularly evident in the state sector.

The Further Mathematics Network was formed in 2000 to promote and support the subject. Since then, AS further mathematics numbers have increased by 58% over the past two years, A level further mathematics numbers have increased by 23%, and A level mathematics numbers increased by 6%. The Network consists of regional centres, co-ordinating schools, colleges, universities and local authorities to support students and raise awareness of the benefits of studying mathematics.

"What is the key to the Network's success? … not to take the decline as inevitable but rather proactively to find a solution by coming up with a judicious mix of high quality materials, distance learning and face to face mentoring."

Professor Celia Hoyles
DfES Chief Adviser for Mathematics

The declining uptake of physics and chemistry observed in the UK and many similar countries may seem to reflect a societal shift away from the hard sciences. A similar, apparently terminal decline in interest was perceived in mathematics but there has been a rapid boost in interest and uptake following proactive intervention across the country. There is no reason to assume that interest in chemistry and physics would not similarly increase following appropriate interventions.

This is one in a series of *Opinion Forums* designed to represent the views of CaSE's members, supporters and contacts about current issues in science and engineering policy.

Along with CaSE's other publications, they are available from the 'documents' section of our website at: **www.sciencecampaign.org.uk/documents/archive.htm**

Other Opinion Forums recently published or currently being planned include subjects such as *Funding for Science & Engineering in Universities, Science & Engineering in Further Education; Careers Guidance; Science education in Northern Ireland's schools; and Major Priorities for Science and Engineering in the 2007 Spending Review.*

29 Tavistock Square
London
WC1H 9QU
Tel: 020 7679 4995
Fax: 020 7916 8528

Campaign for Science & Engineering in the UK

Campaign for Science & Engineering is a pressure group aiming to improve the scientific health of the UK.

Our objective is to communicate to Parliament and the nation as a whole the economic and cultural importance of scientific and technological research and development and the vital need for the funding of this research by Government and industry.

We achieve this by meeting directly with ministers, civil servants and advisers in Westminster and Whitehall, as well as in Edinburgh, Cardiff and Belfast; by networking with a wide range of industrialists, educationalists, researchers and academics involved in science and engineering; by commenting in the media and interacting with backbench Parliamentarians to keep science policy at the forefront of the public agenda; and by publishing analyses, briefings and responses to public consultations.

Our work is supported by 1,500 individual scientists and engineers and by a wide range of industrial companies, universities, city financiers, learned societies, publishers and others.

To discover more about our work, please visit our website:

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