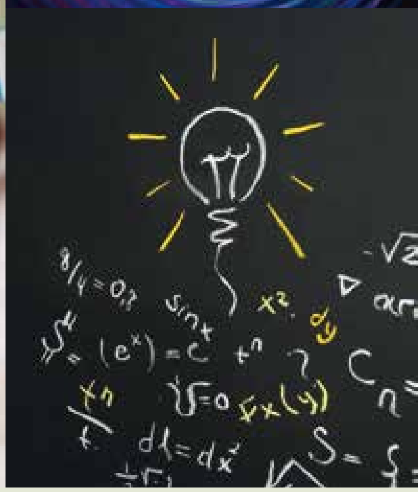
ESRC Targeted Initiative on Science and Mathematics Education

TISME
Researching Science & Mathematics Education

Improving attainment, engagement and participation in science and mathematics

Final report of the Targeted Initiative on Science and Mathematics Education (TISME)



TISME

The Targeted Initiative on Science and Mathematics Education (TISME) is a programme of research funded by the ESRC in partnership with the Gatsby Charitable Foundation, the Institute of Physics and the Association for Science Education. Through research projects and dissemination activities, TISME aims to find new ways to encourage children and young people to greater achievement and participation in – and understanding of – science and mathematics.

TISME is comprised of five research projects:

ASPIRES – *Science Aspirations and Career Choice: Age 10–14*. A five year, longitudinal study of how children develop science and career aspirations, using a national survey of children (Year 6 – Year 9) and interviews with parents and children, based at King's College London.

EISER – *Enactment and Impact of Science Education Reform*. A study of school responses to recent changes in the science curriculum for 14–16 year olds in England, using interviews with students and teachers and quantitative analysis of the National Pupil Database, based at University of Leeds.

epiSTEMe – *Effecting Principled Improvement in STEM Education: Student Engagement and Learning in Early Secondary-School Physical Science and Mathematics*. A study which has designed and evaluated a research-informed intervention suitable for widespread use in ordinary schools during early-secondary education, incorporating key pedagogical features known to improve student attainment and attitude, based at University of Cambridge.

ICCAMS – *Increasing Competence and Confidence in Algebra and Multiplicative Structures*. This study investigated ways of raising students' attainment and engagement by using formative assessment to inform teaching and learning of mathematics in secondary school, based at King's College London.

UPMAP – *Understanding Participation rates in post-16 Mathematics and Physics*. A three year longitudinal study of the factors that cause school students to continue with mathematics or physics after the age of 16, using a UK-wide survey of year 8, year 10 and year 12 students with interviews of year 10, 11, 12 and first year undergraduate students, based at Institute of Education, University of London.

TISME is coordinated by a team of academics from the Department of Education and Professional Studies at King's College London. Further information: **www.tisme-scienceandmaths.org**

Acknowledgements

This briefing paper was written by Warwick Mansell with input from Louise Archer.

Why do some young people persist with studying science, technology, engineering and mathematics (STEM), while others decide not to? What do young people think of these subjects? How successful have policy-makers' attempts been to improve STEM attainment and participation, and what can be done to enhance reform efforts in the future?

These are some of the most important questions currently facing our education system, with big implications both for wider society and the economy.

STEM subjects feature highly on the list of priorities for the attention of education ministers around the world, with research having a potentially powerful role to play in driving change. TISME – the Targeted Initiative on Science and Mathematics Education – was a multi-faceted, five investigation of questions around attainment, engagement and participation in science and mathematics.

In this final report from the initiative, we describe what TISME sought to investigate, what it found and, perhaps most importantly, what its implications are for the future of STEM education. An account of discussion sessions at TISME's final conference, in June 2014, forms the latter section of this publication, as we seek to probe the project's policy legacy.

TISME overview

TISME was a programme of five research projects, funded by the Economic and Social Research Council in partnership with the Institute of Physics, the Gatsby Foundation and the Association for Science Education.

The overall aim of TISME was to uncover new ways to encourage greater participation, engagement, achievement and understanding of science and mathematics among young people.

Between them, TISME's projects covered extensive ground in mapping how young people engage with science and mathematics education, their aspirations for the future, the effects of recent changes to the curriculum and its teaching, and how students' understanding of the subjects might be improved.

The projects were carried out by research teams based at four UK universities: King's College London; the University of Leeds; the University of Cambridge; and the Institute of Education, University of London.

The five TISME projects were:

- ASPIRES ('Children's science and career aspirations, age 10–14'), a longitudinal study of what influences young people's science and career aspirations between the ages of 10 and 14;
- EISER ('Enactment and Impact of Science Education Reform'), an analysis of the effects of recent major changes in the science curriculum for 14- to 16-year-olds;
- epiSTEMe ('Effecting Principled Improvement in STEM Education: Student Engagement and Learning in Early Secondary School Physical Science and Mathematics education'), a trial of a research-informed intervention designed to improve teaching for 11- to 14-year-olds.
- ICCAMS ('Increasing Competence and Confidence in Algebra and Multiplicative Structure'), an investigation of changes in pupils' mathematical understanding over time, trialling a possible approach to improved teaching;
- UPMAP (' Understanding Participation rates in post-16 Mathematics And Physics'), an investigation of students' views and choices at secondary and HE level;

The individual projects are described in detail on the following pages.

ASPIRES (Science Aspirations and Career Choice: age 10–14)

Based at: King's College London

Questions investigated by the research

How open are young people to a career in science? What do they think about studying the subject at A-level?

How are their science aspirations formed over time? How do these aspirations get shaped by their peers, parents and their own experience of science education; and how are these aspirations shaped by gender, social class and ethnicity?

How were the questions explored?

ASPIRES was a five-year, longitudinal study which explored the science aspirations and engagement of tens of thousands of 10- to 14-year-olds. The age group was chosen as evidence shows that the end of primary and start of secondary education is a critical time for the development of children's views of science.

A cohort of students was surveyed and, in some cases, interviewed as they progressed from the end of primary school (aged 10 or 11) through to the cusp of their GCSE courses (aged 13 or 14).

More than 19,000 surveys were completed by students over the course of the project: 9,319 in Year 6 (aged 10/11), 5,634 in Year 8 (aged 12/13) and 4,600 in Year 9 (aged 13/14).

A sample of 83 students and 65 of their parents were also tracked longitudinally, that is interviewed individually and repeatedly over the five year study, to generate an in-depth understanding of how their science and career aspirations develop over time.

In addition to researching influences on students' aspirations, ASPIRES worked with a small group of London teachers to develop approaches for integrating STEM careers information into Key Stage 3 science lessons.

What did the research find?

1. Liking science is not enough. ASPIRES findings show that most young people report liking school science from Year 6 through to Year 9; have positive views of scientists; and say that their parents think it is important for them to learn science. However, the majority of 10- to 14-year-olds – 85 per cent – do not aspire to become scientists.

2. Family 'science capital' is key. Families exert a considerable influence on students' aspirations. A key factor affecting how likely a student is to aspire to a science career is the amount of 'science capital' a family has. This term refers to the science-related qualifications, understanding and knowledge of science, interest in the subject and social contacts such as knowing a scientist that a family has. Families with high levels of science capital are often, though not always, middle-class.

3. Most students and families are not aware of where science can lead. ASPIRES found that the widespread view – that science qualifications lead primarily to a job as a scientist, science teacher or doctor – is contributing to many young people seeing post-16 qualifications as 'not relevant for me'. Those who are aware that science qualifications have a usefulness beyond such careers are more likely, ironically perhaps, to be interested in science careers themselves.

4. The 'brainy' image of scientists and science careers puts many young people off. More than 80 per cent of young people in the surveys agreed that 'scientists are brainy'. This association influences many young

people's views of science careers as 'not for me', with those who do not consider themselves as among the 'brainiest' in the class being unlikely to see science careers as achievable.

5 The male, middle-class image of science careers remains a problem. A student is most likely to express science aspirations if he is male, Asian, comes from a socially advantaged background and is in the top set for science. A student is least likely to aspire to a career in science if she is female, white, comes from a socially disadvantaged background and is in the bottom set for science at school. Gender issues are evident from a young age. Factors hindering students from developing science aspirations are amplified in the case of Black students, due to the multiple inequalities they face.

Recommendations for policy

1 Shift the policy discourse: from "increasing interest" in science to "building science capital". ASPIRES findings show that STEM participation issues are not simply the result of students not liking science enough.

2 Earlier intervention – from primary school. Efforts to broaden students' aspirations, particularly in relation to STEM, need to begin at primary school. The current focus of most activities and interventions – at secondary school – is likely to be too little, too late.

3 Break the "science = scientist" link. Emphasis needs to be directed at broadening young people's views of where science can lead, promoting the message that science "keeps your options open" and is useful for a wide range of careers.

4 Embed STEM careers awareness in science lessons. Embedded models of careers education, in which curriculum learning is systematically linked to real life careers and applications, has been found to raise student engagement and attainment. Funders of research might consider supporting a UK trial of an embedded careers education model.

5 Tackle multiple inequalities. The factors which prevent a student from seeing post-16 science qualifications and careers as "for me" are amplified by social inequalities. Resources should be targeted at disadvantaged students, and educators supported to challenge unconscious bias.

6 Challenge the "brainy" image of science/science careers. Access to science qualifications at GCSE and A-level is more differentiated and restrictive than for other subjects. We suggest that these practices could usefully be re-thought in order to widen participation and ensure more equitable access.

7 Build science capital with students and families. Supporting families to feel comfortable and knowledgeable about science and to see its relevance to their everyday lives and futures might help more students, particularly those from under-represented groups, to develop and sustain science aspirations.

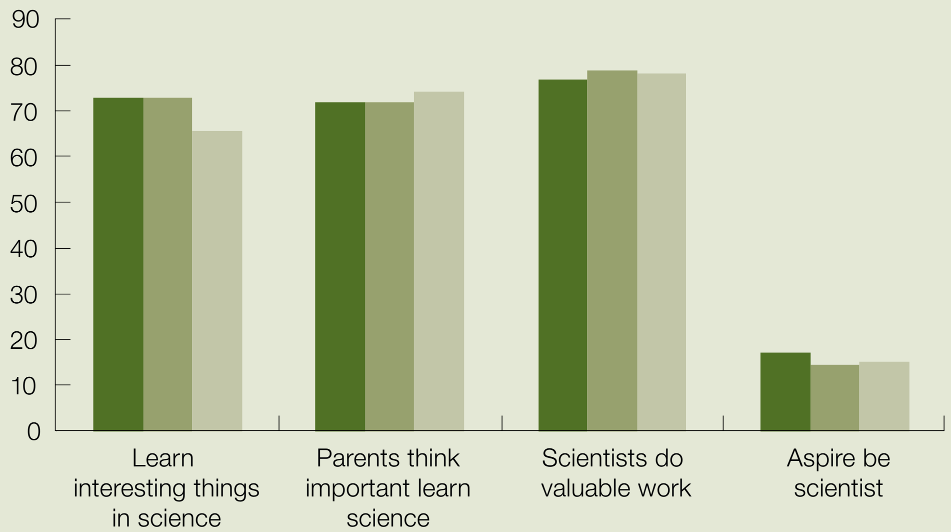


Figure 1. Comparison of survey responses from Y6, Y8 and Y9 students (%strongly agreeing)

EISER (Enactment and Impact of Science Education Reform)

Based at: University of Leeds

Questions investigated by the research

Since 2006, schools in England have been responding to major changes in the science curriculum for 14- to 16-year-olds, which have made available a wider variety of science courses, with more emphasis on applied science and teaching about socio-scientific issues.

How have schools responded? What have been teachers' experiences of enacting the – reformed – science curriculum in the classroom? What has been the initial impact of these reforms on student achievement, attitudes towards science education and participation in post-compulsory science courses?

How were the questions explored?

The EISER study combined national data using the National Pupil Database with in-depth school-based case studies. Data was collected over a three-year period, enabling a longitudinal analysis of the impact of these reforms to be carried out.

England's national pupil database, incorporating assessment data and background information on all pupils in maintained schools, was analysed for five successive Key Stage 4 cohorts. The aim was to investigate patterns of pupil participation and attainment across Key Stages 4 and 5; how these changed over the period of the curriculum change; and to explore possible influences on participation and attainment.

Separately, interviews and questionnaires gauged the views of both students and teachers.

Students were interviewed in 19 schools around England, with two group interviews taking place in each school. More than 2,000 Year 11 students, aged 15 and 16, in 18 schools, were sent questionnaires.

A sample of 56 teachers, from 19 schools, were interviewed during each of three years, covering the third, fourth and fifth years of the reform. The questionnaire was completed by 533 teachers from 107 schools.

A review of publicly available documents was also carried out.

What did the research find?

1. There was a significant diversification of provision for students, with the dominant course, double award GCSE, declining in popularity and both triple award science (biology, physics and chemistry) and applied courses such as BTECs and OCR Nationals seeing their entries rise sharply.

2. There was some stratification in provision, as pupils with higher levels of prior attainment headed in greater numbers for triple award science, while those with lower previous results increasingly took applied qualifications. Results from qualifications completed in 2008 underline this point: on average, pupils taking physics GCSE (on the triple science route) achieved grade A, those entered for double award/additional science GCSE got Cs while those taking additional applied GCSE were awarded, on average, grade Es.

3 The triple award science became more balanced in terms of entries between boys and girls, over the period, with the proportion of girls on this route rising from 41 per cent for courses starting in 2005 to 45 per cent in 2008.

4 Pupils from disadvantaged backgrounds tended to do less well at Key Stage 4, even when controlling for their prior levels of attainment at Key Stage 3. They were less likely to be studying triple science, even when controlling for prior attainment. This raises questions as to whether expanding triple science will mean an increasing stratification by social class.

5 The diversity of qualification routes supported by the reforms seems a good match with students' varied views: different young people want different things from school science. Those taking applied science and core science were more likely to talk about the importance of useful science; those taking triple science favour "traditional science" content, but also appreciate socio-scientific issues (SSI) topics. Those taking triple science are much more likely to agree with the statement "learning science will be useful in my future career" (65 per cent agree or strongly agree) than those on the dual science (45 per cent) or applied and core science (35 per cent) routes.

6 Many students, particularly those taking applied and core science, reported limited experience of discussion and socio-scientific issues in the reality of their lessons. This finding suggests the aims of qualifications reforms might often not be achieved at classroom level.

7 Teachers' responses to the reforms were very varied. On average, the questionnaires found that 47 per cent of teachers were either "positive" (13 per cent) or "positive with reservations" (34 per cent) about the reforms, compared to 17 per cent being "disappointed", six per cent being "negative" and five per cent "initially sceptical". Some 61 per cent agreed the reforms had helped them meet the needs of their students, compared to 28 per cent who disagreed. But many teachers were still developing their response after four to five years.

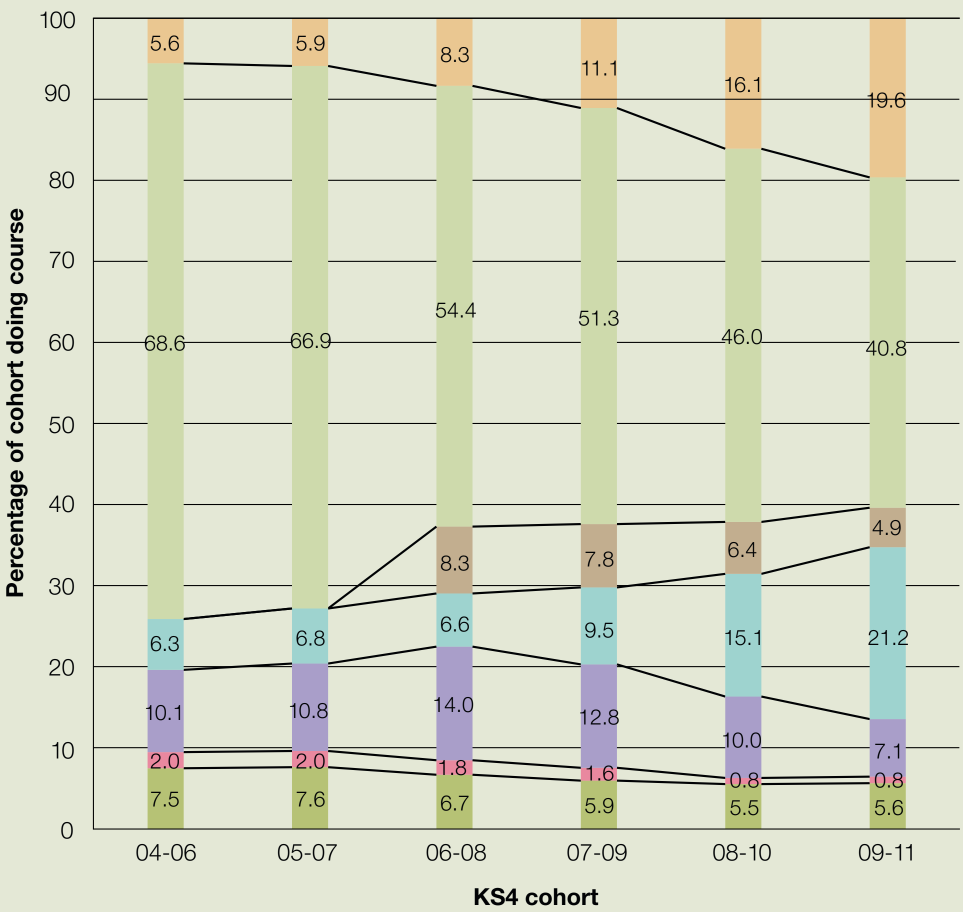


Figure 2. EISER qualifications over time

8 Personal and institutional priorities conditioned teachers' views of the reform, particularly as to whether teachers agreed or not with the emphasis on science for citizenship.

9 The document review suggests not enough consideration was given to the differentiated character of the teaching community; or to involving all stakeholders in reform, including those who would later criticise the GCSE reforms as "dumbing down"; and that the "political" timescale for its introduction was too short.

Recommendations for policy

1 Policy-makers should recognise the possible tension between providing flexibility and increasing stratification by social class.

2 Policy-makers should enhance the prior attainment of students eligible for free school meals/ pupil premium.

3 Policy-makers should examine the longitudinal impact on progression, attainment and value-added of the policy "push" for more students to take triple science at GCSE.

4 The notion of flexibility of course provision, to meet the varying needs and interests of students (and their teachers) is important.

5 Teachers should make explicit the usefulness and relevance of school science in order to have a more positive impact on students.

6 Teachers' commitment and expertise regarding innovations in the curriculum (such as discussion based on SSIs) make a big difference to students' experiences.

7 Time and money for teacher development surrounding curriculum reform would increase the confidence of teachers and impact positively on the student experience.

8 All stakeholders need to be involved in reforms, including those who otherwise might be inclined to criticise them. To this end, policy-makers should convene a "standing" curriculum reform body representing all stakeholders.

9 Policy-makers should plan an appropriate timescale for implementation and evaluation of reforms. Reforms should be piloted in multiple school settings.

10 Policy-makers should consider the reform's interaction with other education policies, such as school accountability measures.

epiSTEMe (Effecting Principled Improvement in STEM Education: Student Engagement and Learning in Early Secondary-School Physical Science and Mathematics)

Based at: University of Cambridge

Questions investigated by the research

Can a carefully-designed, research-informed teaching intervention improve pupils' understanding of science and mathematics at early-secondary level?

How was the question explored?

The epiSTEMe project designed a research-informed intervention which sought to improve the teaching of mathematics and science.

The project comprised three main phases of development and evaluation, followed by a final phase of evaluation.

In phase 1, researchers collaborated with teachers in five schools to devise a teaching intervention for key topics in Year 7 mathematics and science. The resulting teaching modules were designed according to what the international research base tells us about the most effective pedagogy in school mathematics and science. The following components were identified as being particularly effective: domain-specific enquiry, which poses authentic problems and takes student thinking seriously; co-operative and collaborative group-work, as long as students are properly prepared and activity well structured; enhanced context in which teaching makes strong links to student interests; and active teaching (of the type informing the former National Strategies' model of direct interactive teaching).

epiSTEMe also emphasised dialogic teaching: teachers using discussion to identify and examine different students' points of view as to a particular mathematical or scientific problem.

The classroom intervention consisted of an introductory module preparing students and teachers to use the core dialogic teaching approach and two topic modules in each of mathematics (fractions, ratio and proportion; probability) and physical science (forces and proportionality; electricity).

In phase 2, the focus was on classroom intervention by the teachers who had been involved in development, with the results evaluated and the intervention refined accordingly.

In phase 3, a randomised field evaluation took place in 65 classrooms across 25 newly recruited schools. The project provided participating teachers with 2 days of professional development to support implementation of the intervention – in line with current norms for the level of support for this type of innovation.

Evaluation involved qualitative analysis of classroom interaction and quantitative analysis of measures of student attitude and achievement, examining links to student characteristics and classroom processes.

What did the research find?

1 From the field trial, for only three of the four topics (Forces, fractions and probability) were students in the epiSTEMe intervention found to make greater learning gains than those subject to schools' normal teaching.

2 For one of the four topics (electricity), the intervention group made learning gains lower than those of the control group.

3 Within the intervention group, the level of implementation of dialogic teaching was generally higher in mathematics – particularly for the probability module – than in science.

4 Within the intervention group, the size of class

learning gains was positively associated with the level of implementation of dialogic teaching in mathematics but not in science.

5 In terms of whether epiSTEMe made students more inclined to report feeling engaged with the topics taught, there were few statistically significant differences between the intervention and control groups. The exceptions were in probability, where students in the intervention group rated their experience better in terms of seeing the value and application of the topic; and in electricity, where intervention students reported being made to think hard, though registering lower interest in the topic.

6 Broadly, a student's background – their gender, ethnicity, socio-economic status and English-language status – had little impact on the findings above.

7 Comparing the success of classes participating in the developmental and trial phases of the project suggests that the more substantial and extended professional development provided to teachers in the developmental phase produced greater success.

Recommendations for policy

1 Policy regarding mathematics and science teaching should have regard to the strong support that the international research base provides for the effectiveness of domain-specific enquiry, co-operative and collaborative group-work, and active teaching.

2 At the same time, such policy should not underestimate the challenge of translating ideas and findings from the research literature into everyday practice.

3 Dialogic teaching is a wholly viable approach, but improved outcomes cannot be counted on in the early stages of development.

4 Implementing the mathematics component of the epiSTEMe intervention provides a proven means for schools and teachers to develop a more dialogic teaching approach and improve the learning gains of students.

5 The scale and scope of professional development for teachers appears to be a crucial variable affecting the overall success of initiatives and interventions of this type.

ICCAMS (Increasing Competence and Confidence in Algebra and Multiplicative Structures)

Based at: King's College London

Questions investigated by the research

In what ways do current Key Stage 3 students understand key concepts in multiplicative reasoning and algebra?

How do current students' understandings of algebra, decimals and ratio compare to those of their predecessors from the 1970s?

Can a research-informed approach to the teaching of the subject be designed to improve students' understandings of these key ideas?

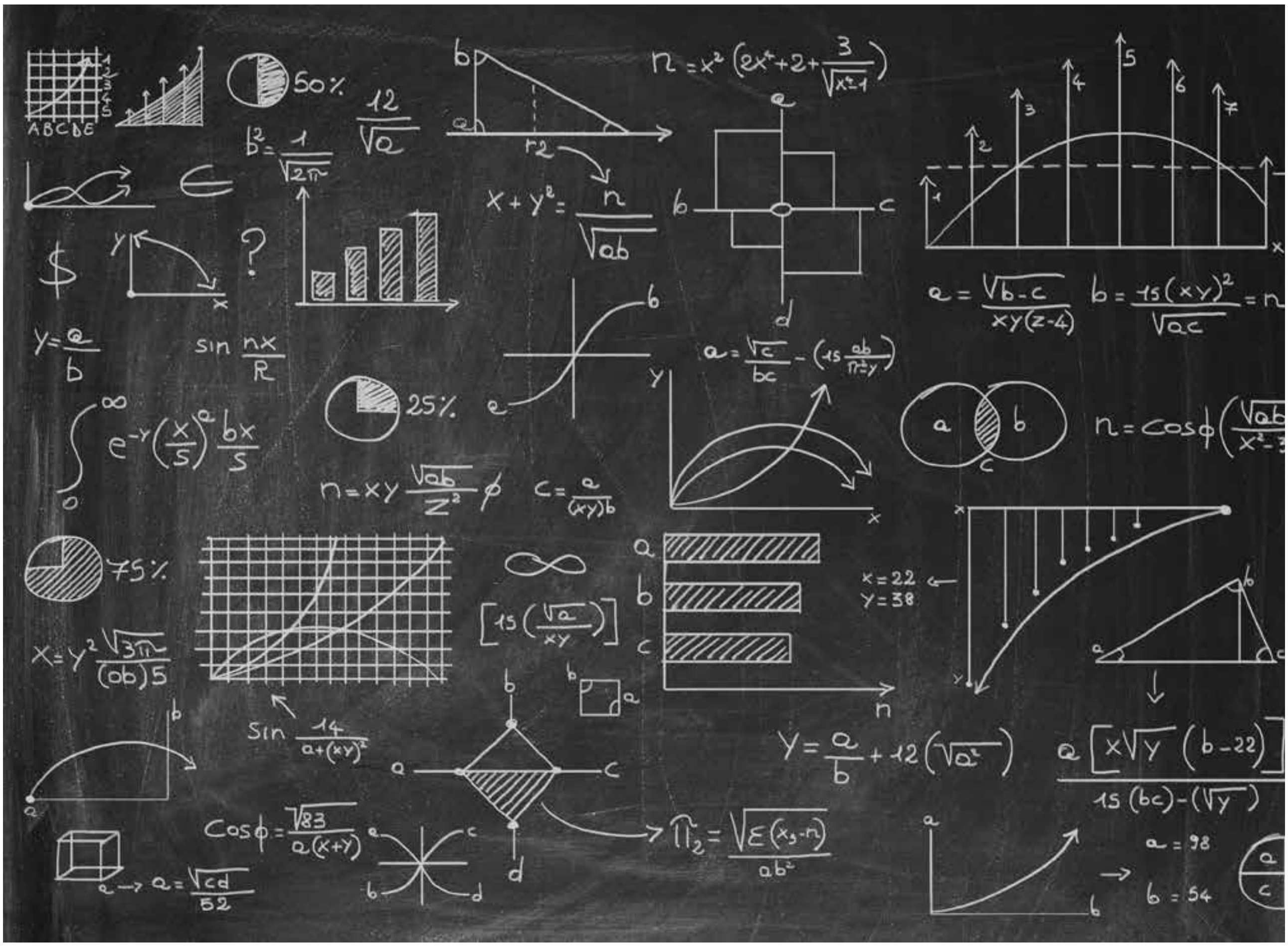
How were the questions explored?

In phase 1, a representative national survey of mathematical understanding in algebra and multiplicative thinking among Key Stage 3 students in England was conducted.

Over two successive summers, in 2008 and 2009, approximately 7,000 students were tested. ICCAMS used tests of algebra, decimals, ratio and fractions which were originally devised for the Concepts in Secondary Mathematics and Science (CSMS) study and taken by students in the 1970s. The survey provided up to date information on current students' mathematical understandings, rates of progression and differences in attainment across the cohort. In addition, the survey allowed for a unique comparison of students' understandings over time.

In phase 2, the project team worked with a group of teachers to investigate whether research evidence on the teaching and learning of mathematics could be used to design an intervention to address the findings of the phase 1 survey and improve both attainment and attitudes to mathematics. This intervention was designed to enable teachers to use formative assessment by evaluating what students already knew, or not, and adapting their teaching to students' needs by using evidence-based approaches.

In phase 3, the intervention was trialled on a larger scale with a further group of 20 teachers and Year 8 mathematics classes from 10 schools.



What did the research find?

1. Students' understandings of algebra, decimals, ratio and fractions are, with some exceptions, weak across Key Stage 3.

2. Attainment in general has not improved over the past 30 years. A comparison of the test results of 2008 and 2009 with those of 1976 and 1977 shows that attainment has not improved over this period and for some groups of students, it has fallen substantially. The only exception is for decimals where attainment has risen slightly for average attaining students, although this rise is small and is not found in relation to the lowest- and highest-attaining students.

3. In algebra and ratio, the proportion of students at the lowest level of attainment has increased significantly. In ratio, the lowest attaining group grew from 7% in 1976/7 to 15% in 2008/9. The proportion of students at the lowest level of attainment in decimals has also increased, while the proportion of the highest attainers has fallen in algebra, decimals and ratio. Across all the topics tested, students perform better on more routine than on non-routine problems.

4. In terms of measuring pupils' progress between Year 7 and Year 8, and between Year 8 and Year 9, learning gains are positive but small. On all three tests, the learning gains were smaller between Year 8 and Year 9 than between Year 7 and Year 8. Gains for low attainers were much smaller than those for middle and high attainers and, as a result, the attainment 'gap' widens across Key Stage 3.

5. The intervention was successful in enabling teachers to adapt their teaching to students' needs by using research-based teaching strategies.

6. Attainment in mathematics can be improved. The intervention designed by ICCAMS researchers and teachers doubled the rate of learning over an academic year.

Recommendations for policy

1. One big message from phase 1 of the project is that effecting system-wide improvements in attainment is difficult. Despite all the initiatives over the period, including the national curriculum, the advent of Ofsted and the introduction of national assessment, in their entirety they have not resulted in improvements to overall mathematical attainment. Indeed, despite the good intentions of these initiatives, mathematical attainment has decreased slightly since the 1970s.

2. We need to have realistic ambitions for educational reform. Initiatives directed at producing relatively small but incremental changes may have more potential for lasting effect than reforms directed at achieving system-wide transformation.

3. Phase 2 shows that successful change is possible. Replicating this at scale is not straightforward and resources need to be directed towards researching how promising interventions like ICCAMS can be implemted on a larger scale.

4. The evidence base on "what works" for all students in secondary mathematics needs to improve. It will be particularly important to provide convincing evidence to schools and teachers of the efficacy of such approaches for low attainers.

5. More research is needed to investigate how to improve attainment of the lowest attainers. A worryingly high proportion of students at age 14 got almost nothing correct on the tests. Yet there is surprisingly, and worryingly, little research on low-attainers. ICCAMS findings suggest that strategies used to try to improve low attainers' grasp of mathematics over the past 40 years have not worked

6. Resources should be developed to support teachers and schools to offer an appropriately challenging mathematics to all students, particularly low attaining students.

UPMAP (Understanding Participation rates in post-16 Mathematics And Physics)

Based at: Institute of Education, University of London

Questions investigated by the research

Why do students continue, or not, with the study of mathematics and physics after the age of 16?

How were the questions explored?

The research had three strands.

In Strand 1, 23,000 students completed questionnaires in either Year 8 or Year 10 which were designed to explore the relationship between students' subject performance, confidence and intrinsic and extrinsic factors, such as interest in what is studied or views as to its usefulness, in each subject and across the two subjects. Some 7,000 of these students then completed these questionnaires two years later. Teachers also completed questionnaires in the 141 project schools.

In Strand 2, the team worked with 12 of the Strand 1 schools in more depth. In each of these schools, interviews were undertaken with six students when they were 15 years old, 16 years old and 17 years old. Issues explored included: student views on the role of parents and other significant adults, peers, teachers and out-of-school experiences on subject choice; student understandings of the nature of mathematics, physics and, as a comparison, English; student views on their abilities in mathematics, physics, English and their relationships to the subjects.

In Strand 3, the team interviewed 51 first year undergraduates under the age of 21 across four higher education institutions. Half had started courses in accountancy, mathematics, engineering or physics, and half had started other degrees but had qualifications that would have allowed them to study the above subjects. The interviewees were asked about their experiences of and feelings about their education, their family and occasions when they had made decisions about their future.

What did the research find?

Young people are more likely to continue with mathematics and/or physics after the age of 16 if:

- they have been encouraged to do so by a key adult (usually in their family or at their school). It does not matter if this adult is good at physics or mathematics, but they should believe that the subjects are worth persevering with, and that the young person can succeed;
- they believe that they will gain from studying the subject in terms of job satisfaction and/or material rewards;
- they have a good understanding of the subject(s);
- they have been well taught.

Recommendations for policy

1 Overall, UPMAP underlines the importance of deep conceptual understanding, accompanied by long-term relationships with excellent teachers.

2 Students need good teaching, and not too many changes of teachers.

3 While building understanding is important, UPMAP shows that extrinsic motivation to want to continue with the subjects – students realising that studying mathematics and/or physics is important in terms of having a career, earning a good salary and generally opening up opportunities for them – is also vital. Policy-makers, and schools, should communicate this potential broadening of horizons to young people.

4 Given that the research shows the importance of a significant adult – which could be a teacher, but is often a family member – in young people's decisions over whether or not to continue with the subjects, adults, including teachers, should be encouraged to talk to students, and to show genuine interest in their futures.

5 UPMAP's findings show no major differences, in terms of what influences young people to keep studying physics or mathematics, between the two subjects, or indeed between males and females. This suggests that policy-makers and schools do not need to tailor the majority of messages and policies to different sets of students.

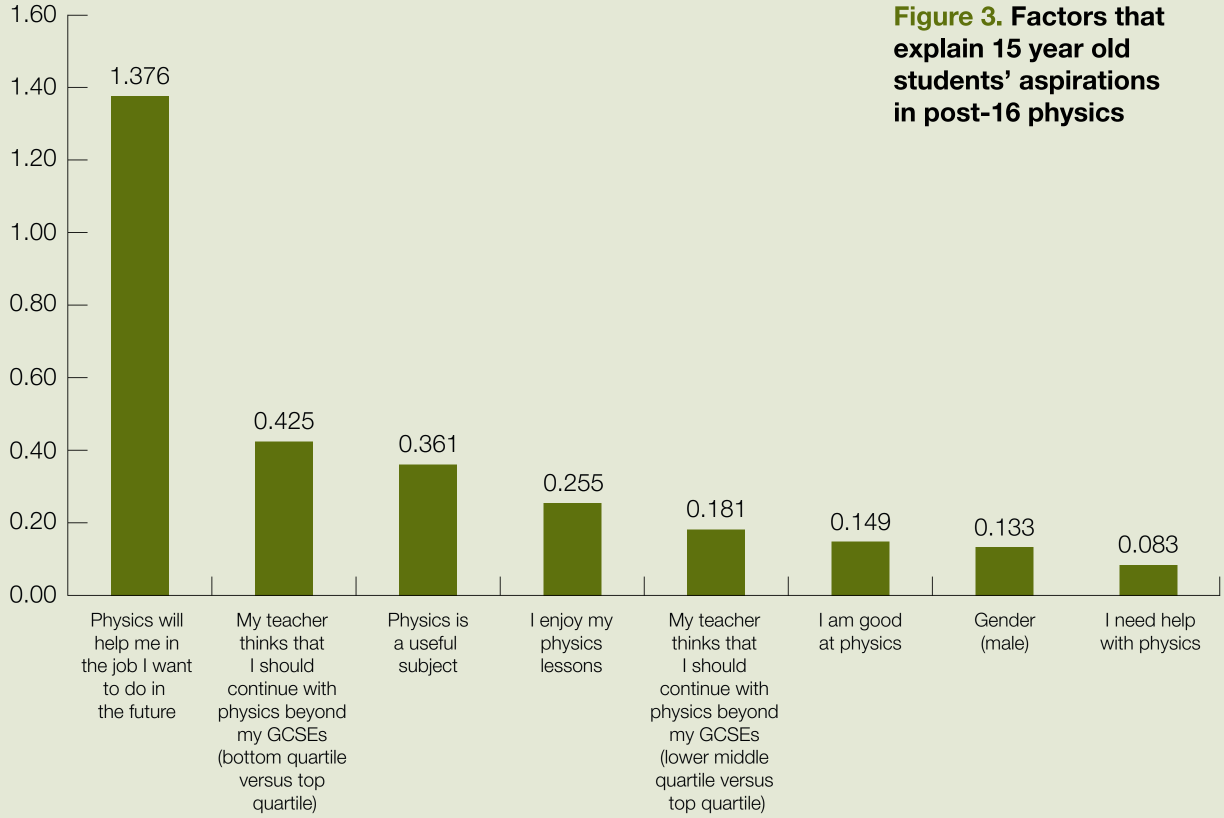


Figure 3. Factors that explain 15 year old students' aspirations in post-16 physics

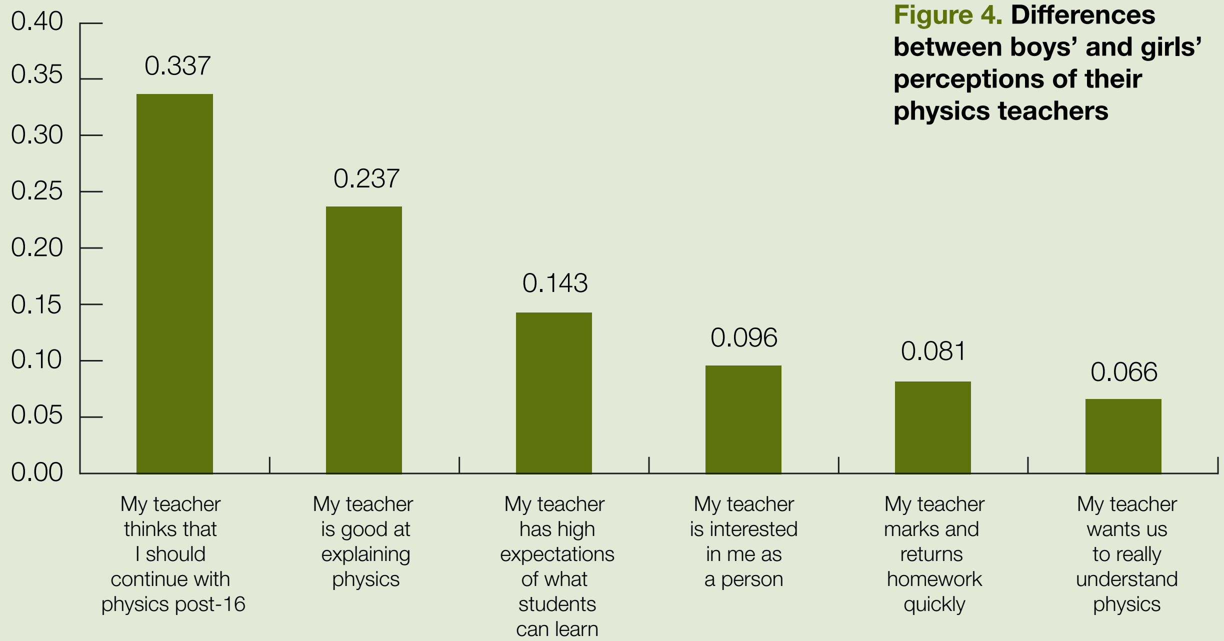


Figure 4. Differences between boys' and girls' perceptions of their physics teachers

Building on TISME: the future

Where do we go from here? What might a "roadmap" for the future of STEM education and its associated research look like? And how can we build on the lessons learned from TISME, with its five highly detailed research projects?

These were among the questions which were considered at TISME's final conference, on Tuesday, June 10th, 2014. Entitled "Choosing our Futures: A Roadmap for STEM Education" and held at the Queen Elizabeth II Conference Centre in London, the conference featured leading names from UK science education, with keynote speeches from the science broadcaster and academic Lord Winston and Andreas Schleicher, of the Organisation for Economic Co-operation and Development, as well as an introduction from Elizabeth Truss MP, who at the time was the minister with responsibility for STEM at the Department for Education.

There follows a brief summary of the keynotes, after which we devote most of the rest of this paper to the final session, when the important question as to the future of STEM education in the light of TISME was debated explicitly.

Elizabeth Truss, at the time parliamentary under secretary of state for education and childcare, used her introduction to the two keynote speakers to highlight the work the DfE was doing with regard to STEM. One of the Government's ambitions, she said, was to "change [the] attitude" among many young people that said STEM was "dull, boring and male".

TISME, she said "has done a lot of work to understand the factors that influence participation in engineering and science and mathematics", and this was one of the reasons why the DfE was working with "leading innovators in industry" on the "Your Life" campaign.

This initiative, which was being launched in September 2014, would "show off all the opportunities that maths and science can bring" young people. Ms Truss also highlighted two other DfE policies: the introduction of 32 "maths hubs" which will see schools and colleges working to improve subject teaching; and the "maths and physics chairs" programme, in which employees of leading companies who have PhDs in maths and physics help teach in schools.

Andreas Schleicher, the deputy director for education at the Organisation for Economic Co-operation and Development who oversees the OECD's "PISA" system of reading, maths and science tests for 15-year-olds, offered data and interpretation on the economic returns for high performance in mathematics; gender differences in performance; and how young people's "self-efficacy" can affect their ability to solve problems.

Using the OECD's recent measures of adult numeracy skills across countries, Mr Schleicher said they showed that individuals were three times more likely to be employed if they had good numeracy skills and four times as likely to be an above-median wage earner, while there were also positive relationships with health outcomes and participation in voluntary and political activities. These patterns were particularly strong in the UK, he said.

Dr Schleicher also used PISA test data to show that the UK had an about-average gender gap in mathematics, with boys ahead of girls, but that girls from lower socio-economic backgrounds were lagging particularly far behind. East Asian countries, and others including Finland, he said, fared much better both on overall maths performance and on "self-efficacy": the extent to which an individual believed they could "solve mathematical problems they have not seen before". Nurturing this latter quality could have a big impact, he suggested: boys tended to have "higher self-efficacy" in maths than girls and improving that of girls such that it matched, on average, that of boys would close the gender gap in maths performance, as measured by the PISA tests, entirely in the UK.

Mr Schleicher added that East Asian jurisdictions such as Shanghai in China and Singapore, which do very well in PISA, tended to emphasise building deep conceptual understanding among pupils, rather than real-life "word problems in mathematics", where "very simple maths" was "embedded in very complicated contexts". The latter was prevalent in UK maths teaching, he said.

Lord Winston, the well-known broadcaster, human fertility expert and professor of science and society at Imperial College, London, questioned Mr Schleicher's presentation, saying PISA tests might not be measuring all that it was important to measure, such as aspects of a child's personality. A recent trip to Israel, which performed badly in PISA but had a thriving high-tech economic sector, suggested there was "something else than simple mathematical experience" as measured by PISA that was important for economic success.

In terms of areas on which policy should pay attention, he said: "We have a real problem in not really focusing enough on primary education. We know that we are losing children at the age of 10 and 11 and we should do much more to raise the aspiration of primary children early on."

He added that he was currently overseeing a group of 18 student primary school teachers, only one of whom had a science degree, with most not having science A-levels. "But they are having to answer the most difficult questions [from pupils]…primary school science is hard," he added.

Careers and Closing the Gap

The conference's final session saw a panel of speakers expand on the central debate of how STEM policy should develop. In other words, what should be the "road map"?

Keith Herrmann, convenor of the Careers Sector Stakeholders Alliance, stressed the need for **TISME's findings to be actively and enthusiastically disseminated**, before emphasising the importance of **young people being made aware of the transferability of STEM qualifications and knowledge.**

The ASPIRES finding that many people did not see science as "for them" was profound and needed to be taken seriously, he said.

"For me, maths and science are fundamental to future careers thinking, irrespective of the trajectory one takes in one's career," he added.

"Around 50 per cent of STEM graduates end up in non-STEM jobs. But STEM knowledge is crucial in non-STEM areas," he said.

Yet the paths young people took between school subjects, university and careers were complex, and grappling with that complexity was a challenge. Some STEM students at university went into non-STEM jobs because the labour market was favourable, or simply found it interesting to use their STEM knowledge in non-STEM fields, such as consulting or audit.

He said: "There's a real challenge in terms of trying to connect that complexity to what some people see as a very clear, linear way of thinking about STEM careers: [i.e.] 'If you want to be an engineer, well here's the ladder, you climb on here, you progress through these steps, and lo and behold, you become an engineer'.

"It's a lot more complex than that, and therefore, don't be surprised that there is a lot of leakage [people leaving this path] along the way."

One of the aspects that employers and careers professionals needed to grapple with was many students' protracted indecisiveness about what they wanted to do, he said: many students, even six months from finishing their degrees, had "not given a thought" to what they were going to do after graduating.

For Dr. Kevan Collins, chief executive of the Education Endowment Foundation, **closing the exam result gap** between those children who were disadvantaged and those who were not was the priority.

He said: "18 per cent of children who were not eligible for free school meals walked out of English secondary schools last year with five [GCSEs] at A or A*. Some five per cent of children on free school meals walked out with [those results] in their bundle.

"We have this profound issue of the difference in outcomes for children on free school meals and others, and that remains the … anchor on whatever we are going to do going forward. How do you close the gap?"

There were some schools which bucked the trend: about one in seven secondaries did better than the national average for all their children, so it was possible, he said. But how?

Dr. Collins said the key was to **focus on pedagogy**: improving the quality of teaching, based on evidence. In a comment which tallied with a conclusion of the ICCAMS team, he said the key was the quality of *how* a teacher teaches, he said, rather than, actually, *what* was being taught.

He said: "The question is how do you help teachers become more effective in their teaching? How do you build better evidence about what works … how do you make your pedagogy and teaching ever more effective?"

Dr. Collins then highlighted the EEF's Teaching and Learning Toolkit, and how the Foundation is funding randomised control trials aiming to build the evidence base in relation to effective teaching. 600,000 children in 2,000 English schools were now involved in this research.

He added that the "biggest bets" as far as improving teaching was concerned were **improving teacher-pupil feedback; metacognition; and collaboration.**

He also highlighted other strands of work being investigated: a project with 40 schools in Oxford which was exploring improving teacher training and development to make science lessons more conceptually challenging and attractive; research with King's College, London and 53 schools on "cognitive acceleration" in science; work with the Ark Schools academy chain and 150 schools on "maths mastery": embedding mathematical understanding deeply before moving on; lesson study, a method of improving teaching through peer observation and discussion used in Japan; and a National Association of Head Teachers project on using lesson observations in a non-judgemental way for teaching staff.

But the real challenge, he added, was not just finding which teaching approach worked, but in **spreading and mobilising the knowledge of what worked.**

A DfE perspective

Tom Richmond, a senior policy adviser to the Department for Education and the Department for Business, Innovation and Skills, said that, when considering the government's role in supporting the "roadmap" for improving STEM, there were now three priorities.

He said it was important to make sure that the **"right courses"** were available to students; that a **workforce** was in place that could deliver these courses effectively; and that **students knew about STEM careers and STEM-related opportunities**.

On the first priority, Mr Richmond emphasised the Government's "huge reform of qualifications". Subject material had been made more demanding, with computing introduced into the DfE list of "core GCSEs" – through the English Baccaluareate league table indicator – and the primary curriculum, new GCSE science and maths which had "much more stretch and demand" and a "much more demanding" new science A-level.

"There has been a very conscious effort by this government to stretch students further, and to make our exams internationally comparable with the best in the world," he said. "That has been a very direct steer from ministers that that is what they want to achieve."

In addition, he said, ministers were reforming the entire national apprenticeships system, "taking it to a whole new level" and, again, benchmarking it against the best in the world.

Last October, the Prime Minister launched the first eight "trailblazing" groups of companies who would work together to design new apprenticeships. With "fantastic" support from the Gatsby Foundation, these groups already embraced the aerospace, automotive and life sciences sectors, he said.

On the second priority – getting the right workforce in place – Mr Richmond said firms such as Microsoft, Google and IBM have said they are going to train 45,000 teachers to teach the new computing curriculum; the British Computer Society was training several thousand teachers while Computing at School was running workshops to help primary teachers prepare.

Bursaries had been made available to try to "attract the very best graduates into teaching". And companies such as Barclays and Glaxo Smithklein were supporting the "maths and physics chairs" scheme mentioned by Elizabeth Truss, which was designed to get post-doctoral graduates into teaching.

On the third priority – ensuring students were well-informed about the value of STEM courses – Mr Richmond highlighted a string of initiatives: the high-profile "Your Life" campaign, which was being backed by a host of coalition ministers and leading multinational firms; the STEMNET and STEM Ambassadors schemes, also seeking to inspire young people about science; the Tomorrow's Engineers scheme; and the Big Bang Fair, of which

Mr Richmond said "we think it is the largest celebration of STEM across the country".

Teacher professional development

Pauline Hoyle, associate director of Myscience, which runs both the National Science Learning Centre as a centre of excellence for teachers' professional development and the National STEM Centre, said there was a need to try better to understand what seemingly conflicting datasets told us about whether the teaching of science was improving.

She highlighted the vastly improved domestic GCSE and A-level results over the past 20–30 years, and the messages of the OECD's PISA tests for 15-year-olds, where the UK's performance has not registered such an improvement.

Ms Hoyle then said that policy-makers needed to focus on teachers' professional development, and in particular on the importance of involving teachers at the beginning with framing how their own professional development was formulated.

In particular, she said, before a development intervention was made, teachers should "look at where they are in terms of their current practice" and their pupils' levels of understanding, and then seek to measure very carefully how their pupils progressed.

More teachers need to get involved in action research in their classrooms, she said. Post-TISME, researchers also needed to grapple with the different landscape of English education, with the rise of academies meaning this was now a "very different educational environment to that in which TISME started five years ago": "a school-led, self-improving system".

A school leadership perspective

For Malcolm Trobe, deputy general secretary of the Association of School and College Leaders, this was a complex subject, with no "silver bullet" which would address and overcome all of the challenges identified in the TISME studies. "One of the first things you teach youngsters about science is to change one variable at a time," he said. So it was difficult to be sure of the effects of individual initiatives on STEM education, given the fact that so many variables were changing simultaneously.

That said, he offered some pointers, saying that the evidence of the TISME research "certainly strikes home for those involved in schools".

First, he said, pupils' "science capital" was a key issue, meaning it was "very, very important" for schools to **engage parents** in science learning.

Second, it was vital that there were **large numbers of young people, among those who took science at A-level or equivalent, went on to do so at university.**

Third, the school **accountability system** needed to be reviewed. "What's the impact of the accountability measures at the moment on what's going on in education? We are very, very qualifications-focused [in schools and colleges], and the accountability measures have an impact on the subject choice of young people at 13 or 14," he said.

But this focus on qualifications often led to teaching to the test, or "what I have sometimes described as teaching by algorithm, and by formula, rather than for understanding".

Mr Trobe added: "It is that deeper understanding in maths- and science-based subjects that we need for young people to gain that interest and that dynamism to go forward."

He added that, speaking personally, he had "great concerns" about Ofqual's recent move to separate practical work from the overall grading of A-level science, saying it could have a negative impact on both the way science is taught and on future numbers taking the subject.

Fourth, there was a need for a strong **"national message" from politicians** about the importance of science education, and about the value of education more generally. Politicians needed to speak positively about schools. Mr Trobe said: "We need to build up trust in our education service in order to give parents trust in it and also to encourage people to go into teaching."

Fifth, in an acknowledgement of a central finding of the ASPIRES study – that many pupils viewed science as only for the "brainy" and thus not for them – Mr Trobe said **policy-makers needed to promote scientists as role models for young people**. Professor Brian Cox, the former pop musician who, as a physicist, is one of the faces of the BBC's science coverage, could be the model.

"We need more Brian Cox, less boffin," suggested Mr Trobe.

Sixth, schools needed to work with pupils from a young age to encourage their **mathematical** and s**cientific aspirations**. The ASPIRES research showed that enthusing pupils from the age of 10 or 11 was critical. At Bradford Dixons Academy, he said, pupils visited the University of Leeds as they were transferring from primary school, while at the school where he used to be the head, Malmesbury in Wiltshire, where 75 per cent of A-level students did maths, the foundations were being laid with excellent teaching in primary and Key Stage 3.

Seventh, ministers needed to focus on **teacher recruitment**. Tom Richmond, he said, had talked earlier about financial incentives, but "that's not all we should be pushing, because we want teachers who want to engage young people, to engage with science and maths and we want people coming in with the enthusiasm in order to lead our young people".

"So the message from government must be very positive, and we must see the higher education institutions very much engaged with STEM education right the way through, in order to give that motivation [to follow STEM pathways] to young people."

Further reflections and questions

The day's final element, in which the audience asked questions of the panel, offered some more free-ranging discussion as to where STEM research, and its interaction with both classroom practice and policy-making, went from here.

Much of the discussion centred on how to capture what TISME, and STEM research more generally, had learned and to make sure it had impact, although the question even as to the extent of what was known was also discussed.

Tessa Stone, chief executive of the Brightside Trust charity, said there were two different viewpoints being voiced at the conference as to next steps, with some arguing it was a case of “we know masses; how do we deploy?” this knowledge; while others said it was a case of “we don’t know enough”

Christine Harrison, senior lecturer in science education at King’s College London, suggested that what was needed was to consider those initiatives that had been successful and to take them forward now. “Why are we not focusing on that?” she asked.

However, Jeremy Hodgen, who led the ICCAMS research and at the time of the conference was also based at King’s, appeared to disagree. He said: “I would sound a note of caution. One of the things that we found out is that we do not know stuff.

“From ICCAMS, we found out that the things we [governments] have done in terms of the national curriculum, introducing Ofsted, introducing national testing and a whole range of interventions have not halted a decline in terms of levels of [mathematical] understanding since the 1970s.”

“Communicating research to policy-makers and politicians is really quite hard,” he added, while “scaling up things that work” was also very difficult.

“The Education Endowment Foundation is doing something, but there’s a huge task ahead for it.”

Tessa Stone said: “I think we know a huge amount more than we think we do. The big question for TISME was, she said, “how do we consolidate what we know, which is a huge amount, into something programmatic and then test that?”

Peter Main, director of education and science at the Institute of Physics, said that he saw TISME as the beginning of a process of understanding: “It has been groundbreaking in that scientists and engineers have interacted with social scientists and ... this should be the model for future research”.

Pauline Hoyle said that the changed school environment, with England’s 153 local authorities now largely receding as organisations advising teachers in England’s education system and diverse academy providers emerging, made disseminating what we had learned more challenging but also more important.

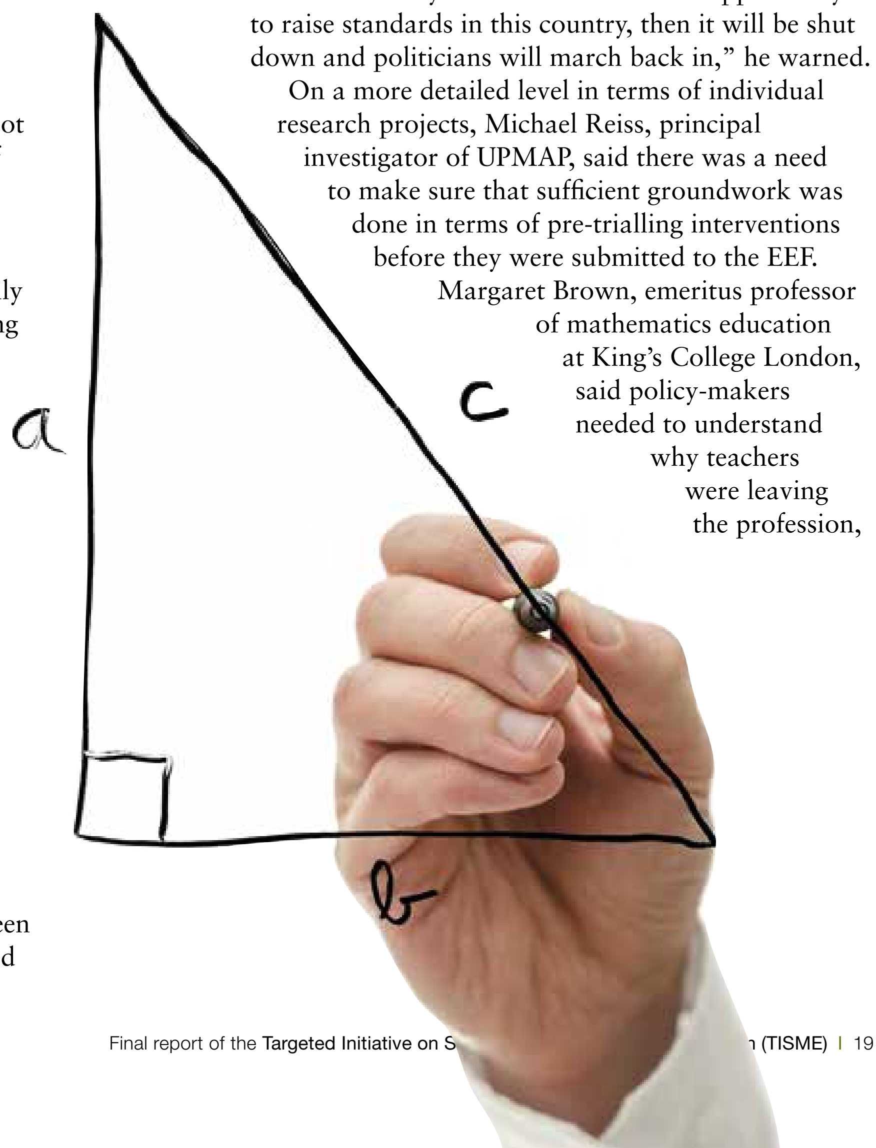
She said: “From my experience, headteachers and senior leaders are really at sea as to who to go to for what works. I think we need to start to engage much more with headteachers and senior managers about what is effective teaching and learning and how we know it.”

Both Kevan Collins and Tom Richmond emphasised the role that the EEF, with its focus on carrying out randomised controlled trials of interventions designed to improve teaching, had in this new environment, with Mr Richmond saying the EEF had transformed the research landscape since 2010.

For Kevan Collins, the move towards a more “school-led” system offered a rare opportunity for teachers to shape what happened in classrooms. “If the school-led system does not take the opportunity… to raise standards in this country, then it will be shut down and politicians will march back in,” he warned.

On a more detailed level in terms of individual research projects, Michael Reiss, principal investigator of UPMAP, said there was a need to make sure that sufficient groundwork was done in terms of pre-trialling interventions before they were submitted to the EEF.

Margaret Brown, emeritus professor of mathematics education at King’s College London, said policy-makers needed to understand why teachers were leaving the profession,



with Kevan Collins quoting the figure of two out of five doing so within five years.

Kevan Collins replied: “What are people who leave worried about? They are worried about the level of support [they get in school], they are worried about the lack of reward – I don’t mean financial reward, I mean the reward professionally, to be an enquirer, to be a learner, to be improving in what you do.” He felt that programmes, such as TISME, need to capture and collate research evidence on, and build understanding of, these issues.

Another area of serious concern for the future was careers advice. Keith Herrmann said: “Sadly, we have a government that has not supported careers education and information, advice and guidance in schools”.

“It has taken away £200 million in funding. Yes, one can argue that Connexions [the service set up under the last Labour government] was not working, but that does not mean one completely dismantles the infrastructure that was supporting careers education and IAG in schools.”

In response, Mr Herrmann said he thought there should be some kind of national framework or “delivery vehicle” for careers education. “We need a programmatic approach to careers education. That’s fundamentally missing at the moment.”

Margaret de Jong-Derrington, a lecturer in computer science and information technology in education at King’s College London, argued that STEM education, and the TISME project in particular, should give more prominence to computing. Professor Louise Archer, lead co-ordinator of the TISME programme, agreed that if there was another iteration of TISME, it would indeed need to focus much more on technology, and engineering too.

Finally, Josh Hillman, director of education at the Nuffield Foundation, asked what the TISME team would do differently if they were starting their research again.

Kenneth Ruthven, who led the epiSTEMe project, perhaps spoke for many when he responded by saying that it was important to focus on teachers’ professional development. He said: “I would have placed much more emphasis on investigating the professional learning of mathematics and science teachers.

“Because the experience of the last five years has indicated that that is the absolutely crucial variable, and really until you get that right, all the other knowledge you have is not really actionable.

“This is the fundamental part of the translation of research-based knowledge into practice. Until you have a teaching force that has good mechanisms that enable it to learn, you are not going to be able to achieve very much,” he added.

A Roadmap for STEM Education Research

We have learned much from the TISME research projects, which have undoubtedly enhanced knowledge and understanding of the issues influencing attainment, engagement and participation in science and mathematics. Drawing across all five projects, and looking ahead to the next five to ten years, we propose the following agenda for STEM education research:

1. Broaden the knowledge and evidence base to technology and engineering. TISME provided a valuable focus on science and maths, and there are some transferable messages for the whole sector, but looking ahead we see the most fruitful path to lie in research which specifically examines and advances understanding on what influences attainment and participation across and between all the STEM areas.

2. Funders should continue to support substantive, longitudinal investigations. The value of a longitudinal picture cannot be underestimated. There may be a particular value in studies that track students from schooling through into post-compulsory education.

3. Further support is needed for development and testing of ‘proof of principle’ projects which aim to find new ways to improve attainment and participation in STEM. Linking between funding bodies, to enable ‘pathways’ for the future larger scale testing out of this work would be valuable.

4. Support is required to (continue to) provide fora and spaces for close, productive working between STEM education policy, practice and research.

5. The sustainable future of STEM education research in the UK is at risk unless we find ways to support capacity building within the sector. Mechanisms are required to ensure that our current STEM education research expertise can, in the long term, be assured of being replenished, invigorated and grown, with researchers who are able to conduct both high quality research and translate these findings into policy/practice.

Acknowledgements

TISME was funded by the Economic and Social Research Council (ESRC) in partnership with the Institute of Physics, Gatsby Charitable Foundation and Association for Science Education. We wish to extend our thanks to all these organisations for their support and engagement with the programme.

Particular thanks to all the project teams, Michele Weatherburn (Department for Education), our ESRC case officers and Andy Furlong, (University of Glasgow) and the various TISME administrators who have helped ensure the smooth running of the project over the past years.

TISME was coordinated by: Professor Louise Archer, Professor Jeremy Hodgen and Professor Justin Dillon, King's College London.

This report was prepared on behalf of TISME by Warwick Mansell.

Further Information

For details of TISME Projects, Publications and Events please see the following:
tisme-scienceandmaths.org

TISME Publications

Brighter Futures: Five ideas for improving STEM participation in England (September 2014). A summary of research-informed ideas for policy from the five TISME projects and discussion of these ideas from our January 2014 conference.

What influences participation in science and mathematics? (March 2013) An overview of the state of knowledge about the key factors that shape the patterns of participation.

Linking Research and Teaching (June 2012) Summarises teachers' and researchers' perspectives about the value of close collaboration, suggesting practical ways that links can be strengthened for the mutual benefit of both parties. Draws on emerging learning from the TISME projects and TISME's February 2012 seminar.

The National Curriculum Review: A synthesis of research evidence from TISME (June 2012). Provides evidence based recommendations for the National Curriculum Review (NCR), drawing on both TISME research and reviews of research carried out by the TISME project teams.

Mapping and Classification of STEM Interventions (June 2012) A 'map' of the discourses structuring the current wealth of interventions aimed at increasing engagement, achievement and participation in mathematics and science.

For details on individual projects and lists of their publications and presentations, please see the following web pages:

ASPIRES
www.kcl.ac.uk/aspires
EISER
www.education.leeds.ac.uk/research/projects/enactment-and-impact-of-science-education-reform-eiser
Episteme
www.educ.cam.ac.uk/research/projects/episteme/
ICCAMS
www.kcl.ac.uk/sspp/departments/education/research/crestem/merg/currentresearch/iccams.aspx
UPMAP
www.ioe.ac.uk/study/departments/cpat/4814.html

Project Administrator, TISME
Tel +44 (0)20 7848 3139
Email tisme-admin@kcl.ac.uk

The Targeted Initiative on Science and Mathematics Education (TISME) is a programme of research funded by the Economic and Social Research Council (ESRC) in partnership with the Gatsby Charitable Foundation, the Institute of Physics and the Association for Science Education. TISME comprises projects based at the University of Cambridge, the Institute of Education, King's College London and the University of Leeds. TISME is co-ordinated by a team of academics based at King's College, London.