Joint response to the Royal Society's call for views: Vision for science and mathematics education 5-19

This response has been prepared by a consortium of the leading Technology Enhanced Learning (TEL) research labs in the UK, in collaboration with the UK's Technology Enhanced Learning research programme and the Association for Learning Technology (ALT).

Summary

We welcome the opportunity to contribute to this Royal Society project. Our response highlights the following key ways in which science and mathematics education could be improved:

- Learning technologies offer unprecedented opportunities to improve learning outcomes for all learners.
- We need to harness the opportunities that such technologies present. Students need to **construct and reflect** on mathematics and science; chalk and talk 'delivery', even if on a whiteboard rather than a blackboard, is not enough, and may be inneffective.
- Learning technologies need to be introduced to all teachers along with an increased focus on pedagogies that exploit digital tools and resources for active learning about science and maths. Such technologies are also effective for supporting communities of practitioners and for CPD.
- Technology can provide an effective mechanism for both formative and summative assessment and is currently under-utilized for this.
- Problems that apply more generally to education must be solved in this wider context and not localised to specific subjects.
- Science and mathematics must be celebrated and teachers across all subjects must be encouraged to take pride in their expertise in their chosen field(s).

General questions

Whilst of course we welcome this endeavour by the Royal Society we are disappointed that the remit of the project does not sufficiently address the important role that learning technologies can play in education in all subjects, including science and mathematics. The UK is a world leader in research that explores how technology can support learning and truly to maximise the success of science and mathematics education in the future, we must harness the opportunities that such technologies present. We note that the working group membership does not currently include such expertise and we believe that the group would be strengthened by including this expertise (Question 1b).

There is a need and opportunity to engage young people in 'personal inquiry' into scientific and mathematical topics so as to give these topics personal meaning and engagement with their lives. That could mean topics that directly affect them (such as fitness and diet), or ones that pique their interest, such as global warming or the effects of pollution on animals. New personal technologies can enable young people to carry out structured investigations – to enhance their understanding of scientific method, and their positive attitudes to science and scientists. Including and beyond young people a central issue is how to enable people without advanced scientific training to engage in the science that affects their lives. This can be achieved through informative media (e.g. BBC) linked to 'learning journeys' that engage people in curiosity-led learning about scientific topics and engaging people in doing active 'citizen science' – to benefit scientific understanding and to engage young adults as participants in active science. In mathematics, the challenge is to unlock some of the exciting mathematical doors that are embedded in our everyday lives – and to create computational systems that allow mathematics learning to become experimental and experiential in ways that were simply impossible before the advent of digital technologies (Question 1b).

We are concerned that the UK is not changing sufficiently with the times. It is as scientists mature that their worth becomes apparent, so we do not yet know if we are still developing the same level of scientific capacity as was the case say 10 to 25 years ago. Teaching of both science and mathematics need to be more inspirational. Cultural change and the underpinning support infrastructure must celebrate scientific endeavour and success. Science education is still very traditional and does not take advantage of the potential offered by technology in the way that practising scientists do in their professional work. Teaching methods need an update and must be seen to be “real world” and relevant to future careers. There needs to be more personalisation to improve every individual's attainment and more active learning to improve the motivation to learn science and mathematics (Question 1b and c). It is important to avoid localising general educational problems to science and mathematics (or any other subject). These problems can only be truly solved by seeing these issues within this wider context (Question 1c).

Current discussions of computing education focus far too much on the needs of computer science degrees and IT employers. Although these endeavours are important, this focus is too narrow. For a science and mathematics education system to best meet the needs of employers and higher education, we need a coordinated system in which young people are engaged in building, testing and critiquing models - as a scientific and mathematical activity. The kind of computational thinking involved is important for everyone. It isn’t only computer scientists who benefit from computational thinking. So much of the natural, artificial and social world makes use of complex information processing systems. We must focus more on computational needs of research across disciplines, including psychology, neuroscience, psychiatry, biology, epigenetic processes, evolutionary processes, medicine and the complexities of social and economic systems. With the topic of this call for views in mind, we would also stress educational processes here, e.g. what information processing allows a brain to support powerful mathematical and scientific reasoning capabilities? Currently there's practically no support for any of this in schools, so people have to start learning at university, which is (a) too late and (b) not something that most university teachers can teach as they are products of this same outdated system. In a recent study of how people interpret computer outputs in their workplaces (Hoyles et al) researchers found that many people were completely unaware of the systems that underpinned their working lives. People need to understand the ideas behind the computer models that are working behind the scenes to gain a sense of empowerment and job satisfaction. Essentially these are the new literacies that people need to be workers and citizens of the 21st century. (Question 1b; Question 1d)

‘High-quality’ science and mathematics education can be found in countries such as Russia, Finland, Germany, Luxembourg, Japan. Key elements of success here include (Question 2a; Question 2b):

- Preventing narrowing too early.
- Ensuring scientific and mathematical literacy are seen to be important for all.
- Ensuring universality: maths and computing are for more than just CS and IT.

Teachers (and the wider workforce)

To make teaching a top career choice, we need exciting and challenging postgraduate courses leading into education. These could, for example, combine research on educational techniques and learning mechanisms with learning about the best available forms of teaching, thereby contributing to the evidence base for sound decisions about policy and practice. Clearly communicating such interesting opportunities might help to attract some who currently go into other fields. Teaching, including mathematics and science, needs to be viewed as a high status profession. (Question 1a; Question 2e)

For admission to initial teacher training, degree class is much less important - being a teacher requires special aptitudes which take time to develop. Mathematics teachers must understand what a mathematical proof is, why proofs are required in mathematics and that the same result can often be proved in different ways. They must be able to diagnose intelligent but incorrect thinking in a very bright students (e.g. coming very close to a correct proof), to avoid killing the potential of bright learners. (Question 2a)

Learning Technologies and Computer Science need to be introduced to all teachers in a way that changes attitudes, plus an increased focus on pedagogies that exploit digital tools and resources for active learning about science and maths. There is almost no focus on special needs - dyscalculia guidance has almost disappeared, and many teachers do not even know about it. The teaching of programming is now just beginning to take off again, as a result of the work of the ComputingAtSchool (http://www.computingatschool.org.uk/)group and others. But the process must not be controlled (Hi-jacked) by educationalists whose main aim is to get more good students into CS degrees and into jobs with IT employers. The need for computationally educated thinkers is just as great and just as urgent in a wide range of other academic disciplines and walks of life. Unfortunately most people now discussing what sort of computing should be taught don't understand that (Question 2d).

The quality of science and mathematics initial teacher training programmes could be improved by making the STEM teachers more of a community of practitioners experimenting and learning about how best to teach their subject. We believe that very bright teachers must be given far more freedom to be creative and to push their learners in directions that suit them, rather than constraining them to fit into a national curriculum that is inevitably a based on compromise. (Question 2e)

Science and mathematics teacher training should take place in institutions where science and mathematics research is happening and in schools. Institutions should be encouraged, or even obliged to introduce potential science and mathematics teachers to the ways of thinking of some of the most advanced and creative researchers, e.g. as guest speakers. (Question 2f). We also need to attend to teachers of other subjects who do not reinforce numeracy in the same manner as they do literacy (Question 2 Other comments).

Keeping up with major aspects of the development of a field is essential for people teaching that field. We noted earlier that teacher training should provide access to the ways of thinking of some of the most advanced and creative researchers. Access to high calibre, inspiring scientists could also help. We should not underestimate the value of web-based video channels such as the Royal Society's own for this. This would ideally continue throughout a teacher's career. The most successful CPD will include a significant peer element. Good practice of any subject needs to be shared and Learning Technology based CPD provides a major possible route. Make the STEM teachers more of a community of practitioners experimenting and learning about how best to teach their subject (Question 3b). The National Centre for Excellence in the Teaching of Mathematics (NCETM) "shows a way forward in terms of creating a community of teachers who are" (https://www.ncetm.org.uk/.): The National Centre for Excellence in the Teaching of Mathematics (NCETM) aims to meet the professional aspirations and needs of all teachers of mathematics and realise the potential of learners through a sustainable national infrastructure for mathematics-specific continuing professional development (CPD). The NCETM provides and signposts high quality resources to teachers, mathematics education networks, HEIs and CPD providers throughout England. At the same time, the National Centre encourages schools and colleges to learn from their own best practice through collaboration among staff and by sharing good practice locally, regionally and nationally. (Question 3b)

The wider workforce of support staff need to be trained to be flexible, for example, we should not underestimate the importance of IT support staff who need to have wider horizons than simply the standard business applications and systems that tend to be embedded into school-based practice. This issue has done a lot of harm (Question 4a). Teaching assistants remain important and could benefit from training in the workplace where learning technologies can provide vital distance learning opportunities and offer quality assurance. TAs provide key support when they encourage learning to talk about what they are doing (Question 4c).

Teachers need to persuade learners about the importance of science and engineering in the wider workforce. This is a job for all of them. They need to be role models (Question 4 - other comments).

Leadership and ethos

The words "role models" cannot be stressed too much - whether the models come from governors, head staff, staff or somewhere else. The more that role models that believe that maths and science are important the more likely will the pupils follow suit.

Skills, Curriculum and Assessment

In Maths some key aspects are missing in the curriculum: an appreciation of how to interpret numbers/statistics including at various levels; common ways of representing data (exploratory data analysis); back of envelope calculations more underpinning for subsequent CS: examples that include complex logic, more binary, sizing problems, common CS algorithms, sources of error. All of this is universal and should be included at all stages. A good teacher will not discourage learners from getting things wrong, because often that's a deep part of learning why something is right. Computer Science is also very much part of Maths and Science and needs to be treated as part of STEM (Question a).

Recent trends and developments in technology as well as a rise in social and collaborative networks have generated an increasing interest in the use of technology as a support for formative assessment. Examples include the use of e-voting systems (Hanley and Jackson, 2006), learner e-portfolios (Kimbell, 2008, Tolley et al.), diagnostic testing environments which offer adaptive, ipsative assessment data for teachers and students over time (Winkley, 2010, Ripley, 2007, Bull and Kay, 2007, Zapata-Rivera et al., 2007), use of handheld devices to capture data (Bennett and Cunningham, 2009), activity logs, timestamps, version tracking, target-setting (Jewitt et al., 2010), self-guided learning (Sainsbury, 2009), learning journals, and so on. Less well-developed, but increasingly emergent, are new forms of e-assessment, which take into account opportunities for technology-supported peer, collaborative, and self-guided learning (for both teachers and learners) using online social networks and read-write technologies such as web 2.0. (Luckin et al., 2008, Elliott, 2007) as well as for increased parental participation (Lewin and Luckin, 2010) via distributed learning networks. (Question b) Technology can support transitions between different elements of the education system (Question c).

Infrastructure

Labs remain necessary but can be supplemented with virtuality. Instead of hoping to re-fashion schools, we now have the opportunity to design computer-based laboratories that can support personalised and shared inquiry within and beyond the classroom (Pea et al., 2011; Mulholland et al., 2011). Mobile devices including smartphones and tablets have become scientific toolkits, combining cameras, environmental sensors, compasses, voice recorders, and position locators with powerful multimedia computers. Networked through high bandwidth phone connections they can enable simultaneous distributed inquiries across many locations. This process of distributed inquiry needs to be managed, so as to enable productive learning through proposing of new inquiries, investigation, analysis, collaboration, and debate. (Questions 1d and e)

Accountability

Science and Maths should be made accountable through the same accountability structures as the rest of education. This is not an SC&M problem. (Question a)

We welcome the opportunity to contribute our views to this consultation and would be happy to provide further detail or oral evidence to the working group. For more information, please contact Professor Rose Luckin [Professor of Learner Centred Design, The London Knowledge Lab, Institute of Education. r.luckin@ioe.ac.uk. 07595116647].

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