A new approach to mathematical and data education

Executive summary

THE ROYAL SOCIETY

The Mathematical Futures programme

The Mathematical Futures programme was launched in February 2020. It set out to answer three core questions:

1. What mathematical competences will be needed for citizens and society to thrive in the future?
2. How should education systems develop these mathematical competences?
3. What changes should be put in place to move towards that future?

The programme was overseen by the Mathematical Futures Board and the Royal Society Advisory Committee on Mathematics Education. This is a summary of the programme's final report.

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To view the full report and to find out more about the Society's work in this area, scan the QR code or visit: **royalsociety.org/mathematical-futures**

Cover image: An example of how data can be used in everyday life: a bubble map showing total number of goals scored by country during the Euro 2024 tournament.

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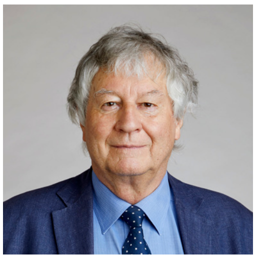


Sir Adrian Smith, President of the Royal Society.

In today's world, mass illiteracy is largely – and thankfully – a thing of the past. However, we are faced with a new challenge – data illiteracy – which risks excluding millions of people from the national conversation and from an increasing number of better-paid jobs. A nation of citizens who lack quantitative literacy represents a potential modern-day threat to democracy and prospects for national renewal.

In our daily lives, we are continually faced with an avalanche of data, figures, numbers and statistics. Digital and data-based technology is also transforming the future of jobs, from finance to engineering and many more sectors.

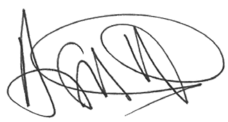
We need to provide a mathematical and data education that better prepares all young people for their futures, whether for jobs in these sectors or to be equipped as citizens to play active roles in wider society.

Confidence in mathematics, in its broadest sense, is essential if we want our citizens, society, and economy to thrive. But we also have a major culture problem around mathematics. As a nation, we need to be more imaginative in how we talk about and teach mathematics – mathematics should not be a frightening word.

We need to work with teachers to create a new curriculum that combines mathematics as we know it with data, computing and AI and that places maths in real world contexts. Core Maths is an excellent, ready-made stepping stone to achieving this. We must also take a serious look at the current assessment system – the psychological toll of resits, for example, is a huge burden on young people.

I am under no illusion – this will not be an easy task. Reforming the education system will take time and major investment. However, if we do not start now, we risk today's young people being ill-prepared for the future, and the exacerbation of existing regional, gender and socio-economic inequalities.

We find ourselves with a once-in-a-generation opportunity to effect change and must begin to build a cross-party approach with support from teachers, students, parents, and employers. This matters too much to be a political football that could be punctured by the ebb and flow of politics.



Sir Adrian Smith,
President of the Royal Society

Introduction

Mathematical and data sciences are everywhere and their influence is growing rapidly. They increasingly support thinking and decisions in government, industry, finance and business, and in academic disciplines. They influence the day-to-day lives of individuals as employees, citizens and consumers of information. The massive increase in the use and availability of data through digital technologies means that this influence can only grow. For all our sakes, our education system must adapt to this rapid change.

In our report, we set out the case for a new approach to mathematical and data education. Throughout autumn 2023, we consulted widely with stakeholders from the teaching profession, universities, employers and business, and with thought leaders and policy makers. The responses demonstrated a high level of agreement that change was needed, and a high level of support for our suggested reforms.

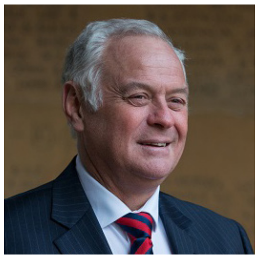
We believe this new approach will equip future citizens with the capabilities, skills, adaptability, and resilience they need to flourish in a fast-changing, data-rich world. We also believe it will result in many more young people wanting to continue with the study of mathematics and data science, leading to a more mathematically-skilled labour force.

The mathematical and data skills needed in this new world will drive some of the biggest public policy solutions of the age, from tackling the climate and biosphere crises to transformative innovation in public service efficiencies, particularly in healthcare. These skills will be an engine of change for tackling persistent inequalities and can re-animate the productivity growth needed to rescue the UK from persistent economic malaise.

However, as we start this journey we face some serious disadvantages. Almost half of all adults have only the numeracy expected of an 11-year-old. A third of pupils in England effectively fail maths at 16 every year, and few improve when they retake the exams. Almost a quarter of UK 15-year-olds fail to achieve PISA Level 2 (eg carrying out a currency conversion), compared to only 15% in Singapore. Only 11% of UK students achieve the higher Level 5 (eg modelling complex situations) compared to 41% in Singapore. Behind all this lie issues of equity. Socio-economic status is strongly correlated with mathematical performance and the gap between bottom and top quintiles has not improved in 10 years.

None of this bodes well for equipping citizens with the skills to evaluate health risks, appraise the likely real costs of payday loans, compete for skilled jobs, start new high-growth companies, or plan well for old age. For citizens, for the economy, and for UK competitiveness, the situation must change.

This report explores how the educational system can respond to the explosion in data availability and the way that the exploitation of data through technologies is pervading every aspect of life. As the world has changed and is increasingly supported on a data-driven architecture, so the teaching of mathematics and data needs to change to equip citizens with the mathematical foundations to thrive as the fourth Industrial Revolution continues to unfold, and the UK grows its economy amidst intense international competition.

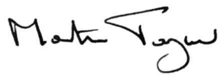


Sir Martin Taylor FRS, Chair of the Mathematical Futures Board and the Royal Society Advisory Committee on Mathematics Education (RS ACME).

Whilst traditional approaches to UK mathematics education had a rationale that fitted the context of the times, that context has dramatically changed. This report explores how a more relevant and resilient future approach can be developed, but it offers no magic bullet or quick win. Success in reforming mathematics education is a decadal project where the new ideas and concepts we describe will need thorough testing by deeply knowledgeable stakeholders from across the education system, and where the strengthened approach that emerges will require sustained investment and considerable commitment.

Our view is that the benefits to individuals and to the nation of succeeding in reform will be profound, and that the policy option to do so is one with no regrets.

The pace of change is fast and is accelerating. Now is the time to act.



Sir Martin Taylor FRS, Chair of the Mathematical Futures Board and the Royal Society Advisory Committee on Mathematics Education (RS ACME)

Executive summary

The case for change – a new approach to mathematical and data education

In the 21st century, the scope and application of mathematics have undergone a remarkable expansion, partly driven by an unprecedented surge in data availability, computing capabilities, and statistical methodologies. Data now plays a pivotal role in both employment and everyday life.

With increased demand for communication, collaboration and problem-solving skills, there is greater need for mathematically- and data-educated people. Mathematical and data literacy has become fundamental for daily life, but too many of our citizens have poor numeracy and too few are trained to the high levels of mathematical and data competence that will be needed in the future. This has serious implications for the future health of the UK economy. The rise of big data, machine learning and AI demands a shift towards statistics, data science and computing.

The scope of mathematical education needs to change from 'mathematics' to what we have called mathematical and data education (MDE); a combination of mathematics, statistics and data science, underpinned by computational tools. MDE has three interconnected elements which, taken together, provide the skills and competences that individuals and society need to thrive:

- **Foundational and advanced mathematics**
  An evolution of the maths currently taught in school, with greater emphasis on data, technology and computing. It will continue to reflect the subject as a canon of knowledge that can be studied to the highest level.

- **General quantitative literacy**
  Addressing the need for all students to confidently apply their mathematical and data skills to common, real-world, quantitative problems in a range of educational, employment and everyday contexts.

- **Domain-specific competences**
  Recognition that mathematical and data skills are increasingly used within the classroom and beyond, in job or domain-specific contexts.

All citizens need foundational mathematics skills and general quantitative literacy for their daily lives. Individuals in vocational and technical roles often need domain-specific competences particular to those occupations, while roles traditionally seen as non-quantitative now require increased mathematical and data skills. At the same time, the demand for employees with advanced levels of mathematical and data skills is already high and is certain to increase substantially.

Mathematical and data education – where are we now?

Across the UK, mathematics education has made progress over the past twenty years. It serves some students well, but lets too many down. There are wide gaps between the lowest and highest achievers, with a long tail of underachievement, linked to economic disadvantage.

Children's progress in mathematics slows as they transition from primary to secondary school, and their attitudes towards mathematics decline. Gaps between high and low achievers widen in key stage 3 (ages 11 – 14). This particularly impacts pupils from disadvantaged backgrounds.

In England, the qualifications and assessment system means that around a third of students leave compulsory education without a GCSE pass in Maths and with an enduring sense of failure, while for many who do achieve a higher GCSE grade there are few appropriate opportunities to continue their mathematical education.

Modern data and computational concepts and tools are largely absent from mathematical education as it is currently practised, while problem solving and application of mathematical learning in meaningful contexts are not given high priority.

There is a long-standing shortage of qualified mathematics teachers, which is most evident in lower secondary years (ages 11 – 14).

The future: mathematical and data education (MDE)

Mathematics is at the heart of mathematical and data education and its importance as a discipline cannot be overstated. Future citizens in all walks of life will need generic, transferrable mathematical competence to underpin their occupation-specific techniques and skills, and to support daily life.

Expert mathematicians

MDE will encourage and nurture future expert mathematical scientists. Students should learn to appreciate that mathematics is one of humanity's great intellectual achievements. For some, the encounter with the fundamental ideas of mathematics will be a gateway to pursuing advanced mathematics – this opportunity should be broadly accessible.

Quantitative literacy

MDE has a strong focus on general quantitative literacy for all learners, at every stage and level, both within the MDE curriculum and across other subjects and qualifications. General quantitative literacy includes real world problem solving where understanding the problem, data collection, mathematisation, performing calculations, and communication of results are all important.

Problems posed in general quantitative literacy do not always have a single 'correct' answer. This is markedly different from current teaching and assessment in mathematics, which typically prioritises mathematical fluency and / or speed. This has implications for teaching and assessment.

Whole-school approaches to mathematical and data education

MDE is embedded in many school subjects, and as students progress, they increasingly need domain-specific competences. These are needed to support different subjects, but also to help understand important, substantive issues such as climate change and sustainability. Consistency of terminology and approach is needed to benefit students, teachers and curriculum planners. Model whole-school MDE policies to underpin consistency and coherence between subjects and phases should be developed. Developing and implementing these policies will involve staff from a variety of relevant subjects, supported by mathematics staff.

Computational concepts, technology and tools

There is a striking difference between mathematics as done in school, and the way it is done beyond school. In employment, higher and further education, and adult life, computation is largely undertaken using digital technology, not by hand. This discrepancy has an effect on the real and perceived relevance of school mathematics. It needs to be addressed both by educational technology that offers tailored tutoring and immediate feedback, and by using computational tools routinely for learning, doing and exploring mathematics.

The interdependencies between computing and mathematics are rich and complex, and they apply in the school context. Mathematics and computing are nonetheless separate subjects, in life and in school, and we expect this to continue. We acknowledge the differences and expect the interdependencies will be fruitfully explored in the future design of MDE.

Stages and structures

In the future, mathematical and data education (MDE) will be a necessary part of everyone's lives. It must therefore provide an appropriate education for all students; one that acknowledges different needs, and start and end points, in a way that our present system does not.

This includes learners with Special Educational Needs, of whom there are around 1.6 million in schools in England. Special Educational Needs can refer to temporary or long-term learning difficulties or disabilities due to a wide range of factors, including communication, cognition and learning, social, emotional, and mental health, and sensory or physical needs. A move to MDE has the potential to benefit many of these pupils, whether it be through the increased use of assistive technologies or through a wider focus on applications and the use of numeracy in life skills. If the aspiration that MDE should be for all students is to be met, then plans for the development of MDE should include explicit consideration of the requirements of Special Educational Needs pupils from the outset.

Early years

High-quality early years mathematical education is critically important for the development of MDE. In the future, there should be greater emphasis on conceptual understanding and a stronger focus on spatial reasoning, which plays a key role in the later development of number, measure, data and geometry skills.

Primary (5 – 11)

Primary teachers are familiar with techniques which develop pupils' knowledge of maths, but the emphasis will have to move to enabling pupils to think, reason and apply their knowledge to solve problems. At present, the curriculum over-emphasises the performance of arithmetical operations but it is the structure of the number system and number relationships that are foundational for future study.

An MDE curriculum would encourage the use of calculators and other computational tools at the appropriate stages to support children's exploration of number, and to enhance problem solving and investigating.

11 – 14

The lack of progress in maths shown by many students during key stage 3 could be addressed by establishing a new assessment around age 14. This assessment would be low-stakes, ie not part of school accountability measures. It would assess competence in fundamental ideas and applying concepts in meaningful contexts.

Students aged 11 – 14 suffer particularly from the shortage of mathematics teachers. MDE should be taught by skilled and knowledgeable practitioners, so creative deployment of expertise already available from teachers of other subjects will be important, as will enhancing these teachers' expertise in mathematical and data education.

14 – 18

From the age of 14, as elements of choice, diverging education pathways, and qualifications with high-stakes assessments are introduced, so the challenge of cross-system coordination of MDE increases. To continue effective mathematical and data education from 14 – 18 requires a coherent structure that recognises different starting points and aspirations.

With the exception of those with the highest grades, GCSE performance currently provides little information about what learners can and cannot do. An essential element of a successful MDE structure will be qualifications and assessment methods that reliably describe the competences of learners.

The curriculum and qualifications structure needs reform to incorporate and recognise all three strands of MDE – foundational and advanced mathematics, general quantitative literacy and domain-specific competences – in different ways and to different extents.

Reimagining qualifications pathways for MDE lies outside the scope of this report, but we suggest some starting points and principles:

- **Foundational and advanced mathematics**
  Requires a structure similar to the one that has existed for many years. The foundational and advanced mathematics strand would foreground a range of mathematical concepts and skills, building sequentially to prepare for transition to undergraduate study of subjects with high mathematical demands, including mathematics itself.
- **General quantitative literacy**
  We envisage a second set of qualifications, designed to develop and assess the ability to use and apply mathematical concepts and use digital tools to address real-world quantitative problems. The existing Core Maths qualifications should be extended and developed as the basis of this strand.
- **Domain-specific competences**
  These already exist in vocational and technical qualifications such as BTECs and T levels and in recently reformed A levels. We expect this to grow and develop.

The developments in general quantitative literacy and domain-specific competences will involve teachers from disciplines other than mathematics. In time, and with appropriate support, general quantitative literacy could be taught by a range of teachers, not just by mathematics teachers.

Teachers

The long-term plans for MDE require investment – financially, politically and culturally – in teacher professionalism. They will depend heavily on a positively disposed teaching workforce across all stages and subjects and must offer teachers sufficient agency to embrace the undoubted challenges that reform will bring.

A new approach to mathematical and data education will require a steadily evolving cadre of teachers who embrace change, not as passive recipients, but as co-creators of a shared, more relevant, ambitious and exciting array of learning experiences, for both students and their teachers.

Next steps

The reforms outlined in this report cannot be developed by limited short-term measures; they will take 10 – 15 years to implement fully and will need planned and coordinated progress on four fronts: curriculum, qualifications, resources and professional development. They will need serious investment and careful planning, design, implementation, and evaluation. They will require collaboration between the stakeholders involved, cross-party support and determination to stay the course.

At the same time, the direction and shape of the long-term changes that are needed are already clear. There are significant risks in delay, and the process should begin as soon as possible.

Recommendations

AREA FOR ACTION 1: IMPLEMENTATION

Education is a complex system that shapes young people's lives and livelihoods. System change must be independent of political ideology and grounded in evidence. Meaningful change takes time, thoughtful planning and steadfastness.

RECOMMENDATION

- The government should sponsor an independent task force to plan for long-term system changes and implement the recommendations from this report. This task force should include relevant government departments such as Department for Education, Department for Science, Innovation and Technology, Department for Business and Trade, and the Treasury. It should also involve senior figures from key stakeholder bodies and should consult with devolved nations. A sufficient budget should be provided to commission exploratory and developmental projects.

AREA FOR ACTION 2: CURRICULUM

What young people learn shapes their perspective on the world. Lessons from past experience and other countries show that curriculum change must be coherent across age ranges and collaborative across subject specialisms.

RECOMMENDATIONS

- Design and implement a curriculum that integrates appropriate data, statistics, and computational tools coherently with mathematics.
- Review the early years and primary curriculum to provide strong foundations, strengthening key areas such as spatial reasoning.

AREA FOR ACTION 3: QUALIFICATIONS AND ASSESSMENT

Assessment is a measure of progress and qualifications are 'passports' to future opportunities. For students, for their future educators and employers, both must recognise what students can do with their learning.

RECOMMENDATIONS

- Develop a single MDE qualifications framework which enables all students to continue to study MDE to 18. Design the framework around parallel and complementary foundational and advanced mathematics and general quantitative literacy strands, with recognition of domain-specific competences acquired in vocational and technical routes. Base the general quantitative literacy strand on development of the existing Core Maths qualifications.
- Develop a low-stakes competency assessment, to be taken by all students around the end of key stage 3 (age 14), to enable individual learners to demonstrate mastery of the foundational MDE concepts and skills necessary for confident and engaged citizenship.
- Develop assessment methods that identify and communicate what students know and can do.
- Develop new methods of assessment for general quantitative literacy that reflect how it is used in practice, including the use of digital technologies to analyse data sets.
- Standardise MDE terminology and level of detail expected in all school and college courses and require awarding organisations to be consistent in how they describe MDE competences in their programmes of study and assessment criteria. Begin this process by carrying out a study into how MDE competences are currently described and used in existing high-stakes qualifications in non-maths subjects.
- Develop online assessment methods that can grow as needed, enabling the use of MDE-specific digital tools and benefitting from lower costs and improved operations.

AREA FOR ACTION 4: COMPUTATIONAL TOOLS AND TECHNOLOGY

Technology and data increasingly shape our world. Students should leave school or college with an understanding of how to use computational tools to interact with the world and understand it better.

RECOMMENDATIONS

- Computational tools and technologies, such as spreadsheets, apps and programming platforms, should be well-embedded at suitable stages within MDE learning. Curriculum designers should ensure these technologies are incorporated to meet the new MDE objectives.
- The Department for Education should carry out a dedicated research programme on the potential impact of AI on MDE learning, identifying new approaches for students at all stages of their education.
- Strengthen the links between MDE and computing by: including problems in MDE that draw on pupils' computing knowledge and skills, including programming; and providing rich, motivating MDE contexts for programming and other skills in computing lessons.
- Ensure advanced MDE students (post-16) develop programming skills and learn the use of computational tools common in mathematically-demanding undergraduate programmes.

AREA FOR ACTION 5: TEACHERS

Teachers are at the heart of a new approach to mathematical and data education and must be central to creation and development of all aspects of this new approach. The successful implementation of MDE will rely on a positive, confident, valued teaching workforce with the agency to drive forward the necessary changes.

RECOMMENDATIONS

- The government should prioritise funding over several years to support a major programme of professional development, including initial teacher training, early career training and continuous professional development to support the implementation of MDE. This should be designed into the implementation plan from the outset and sustained over time.
- Develop professional development programmes, with supporting classroom resources, to enable current teachers to become expert teachers of MDE at key stage 3, and to encourage new routes into teaching.
- Develop ways for mathematics and subject departments in schools and colleges to work with each other to support consistency and coherence between subjects and phases in the teaching of MDE across all subjects; for example, by developing whole-school MDE curriculum guidance documents.

Next steps

The world of education is large and complex. It involves many interconnected strands and long-term change requires planned and coordinated progress on four fronts: curriculum, qualifications, resources and professional development. The history of educational development shows that unless attention is paid to all four strands, failure is likely. In devising our recommendations, we have been very aware of this, and of the way in which they depend on and feed into each other. With the exception of the first recommendation, none are free-standing.

Since the programme began, the appetite for change has developed remarkably. The former Prime Minister's announcement in January 2023 about mathematics for all to 18 was followed by the plan for the Advanced British Standard, while the Labour government elected in July 2024 announced in the same month its intention to begin a wide-ranging review of the national curriculum. Alongside all this is awareness that developments in AI are likely to have important consequences for education, and mathematics education in particular, and that these need urgent consideration. Meanwhile, the response to our discussion paper in autumn 2023 revealed strong support for the direction of change we are advocating, along with a desire to begin the process quickly.

It is, in short, time to seize the moment. The prime recommendation of this report is that the government should establish an independent task force, with a brief to plan for the long-term system changes that will be required and the means to take forward the detailed recommendations set out in this report. To take advantage of the change of government and the opportunities for new thinking this presents, we think this should be set up by early 2025. One of the task force's first jobs will be to begin detailed planning, taking into account the co-dependencies we have described above. Detailed development could begin within a year after it begins working, with work starting on some of our recommendations within six months.

Acknowledgements

Mathematical Futures Board members

The members of the Mathematical Futures Board acted in an individual and not a representative capacity and declared any potential conflicts of interest.

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This report was reviewed by a panel of experts, before being approved for publication by the Council of the Royal Society. The review group members were not asked to endorse the conclusions or recommendations of the report, but to act as independent referees of its technical content and presentation. Members acted in a personal and not a representative capacity and were asked to declare any potential conflicts of interest. The Royal Society gratefully acknowledges the contribution of the reviewers.

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