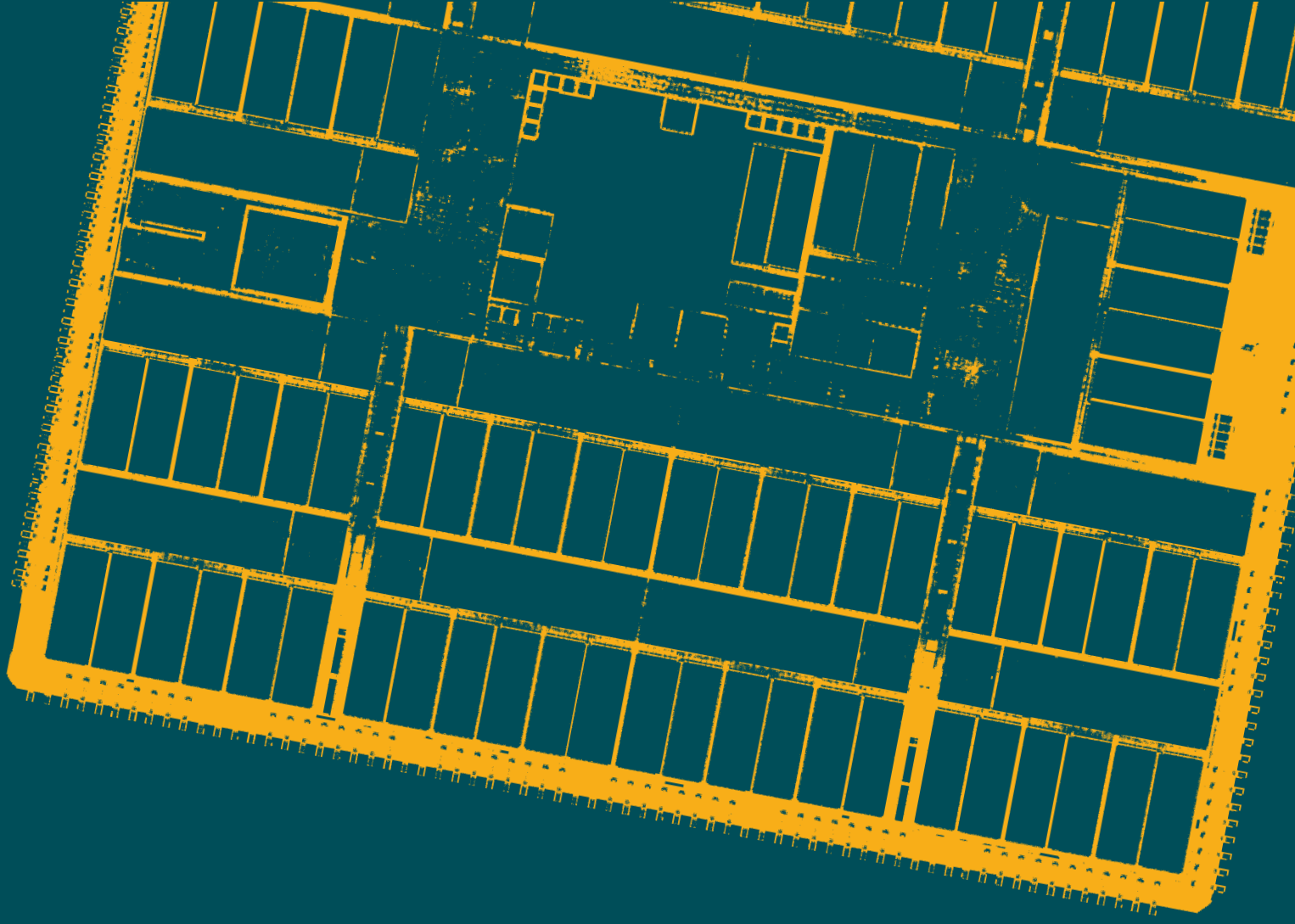

Shut down or restart?

The way forward for computing in UK schools

Executive summary
January 2012

EXCELLENCE IN SCIENCE

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The Royal Academy of Engineering

Steve Furber CBE FRS FREng is the ICL Professor of Computer Engineering in the School of Computer Science at the University of Manchester. He received his B.A. degree in Mathematics in 1974 and his Ph.D. in Aerodynamics in 1980 from the University of Cambridge, England. From 1980 to 1990 he worked in the hardware development group within the R&D department at Acorn Computer Ltd, and was a principal designer both of the BBC Microcomputer, which introduced computing into most UK schools, and of the ARM 32-bit RISC microprocessor, which today powers much of the world's mobile consumer electronics including mobile phones and tablet computers.

Photo supplied by: Millennium Technology Prize.

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A full report is also available on request via the contact details below or online at **royal.society.org/education/policy**

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Cover image: The illustration shows the physical layout of the 1cm^2 SpiNNaker chip, developed at the University of Manchester. The chip incorporates 18 ARM processor cores in an architecture based on, and designed to simulate, the very high levels of connectivity of cells in the brain.

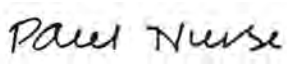
President's Foreword
Sir Paul Nurse FRS

This report analyses the current state of Computing education in schools and sets out a way forward for improving on the present situation. With support from the Royal Academy of Engineering and others the Royal Society has used its 'convening' role to bring together a wide range of distinguished Computer Scientists and stakeholders to explore problems and propose solutions.

Computing is of enormous importance to the economy, and the role of Computer Science as a discipline itself and as an 'underpinning' subject across science and engineering is growing rapidly. This alone is motivation enough, but as this report shows, the arguments for reforming Computing education are not purely utilitarian. It is becoming increasingly clear that studying Computer Science provides a 'way of thinking' in the same way that mathematics does, and that there are therefore strong educational arguments for taking a careful look at how and when we introduce young people to the subject.

The Government has recognised the need for more high quality Computer Science teaching, and has committed to exploring the best ways to achieve this. Our report therefore provides a particularly timely source of evidence that will be needed to inform important policy decisions relating to the National Curriculum in England and to support a drive towards improving Computing education throughout the UK.

I am grateful to Professor Steve Furber for leading this study and to the project Advisory Group for their hard work on this report. I hope that the Royal Society's work will provide a solid foundation which the community can build on, to ensure that the next generation of young people in this country can be creators of technology – not just consumers of it. Just as describing and analysing the problems in this report has been a joint activity, it is clear now that ensuring that the solutions are taken forward is a shared responsibility.



Paul Nurse
President of the Royal Society

Chair's Introduction
Professor Steve Furber FRS

This report is published 30 years to the month after the launch of the BBC Microcomputer. The BBC Micro, and its competitors, introduced a generation to Computing, and I still regularly meet individuals who tell me that the BBC Micro was their introduction to programming and had a significant influence on their subsequent career.

The BBC Micro was the result of an imaginative (and not uncontroversial!) initiative by the BBC, reinforced by an ambitious UK government Computer Literacy project that put computers in every UK school. It has been credited with establishing the UK's strengths in the computer games industry, and clearly led to the establishment of ARM Ltd, the world's leading supplier of microprocessors for mobile consumer electronics.

Computer technology advances rapidly, and the 1990s saw the BBC Micro give way to the PC, a machine designed for business and office use, not for education. At the turn of the century, the government responded to business needs by establishing Computing as a component of the National Curriculum, under the heading of 'ICT' – Information and Communications Technology – a mixture of many related components. The ICT National Curriculum has accommodated a wide range of teaching and content, and in the course of this study we have found examples of imaginative and inspiring teaching under the ICT heading. Sadly, however, these positive examples are in a minority, and we have found far too many examples of demotivating and routine ICT activity, and a widespread perspective among pupils that "ICT is boring". Fears now abound in the Computing community that we have somehow lost our way in recent years. We appear to have succeeded in making many people comfortable with using the technology that we find around us, but this seems to have been at the expense of failing to provide a deeper understanding of the rigorous academic subject of Computer Science and exposure to the opportunities for interest, excitement and creativity that even a modest mastery of the subject offers.

A dwindling enthusiasm for Computing is now widely reported. Some even go so far as to say that it would be better not to try to teach Computing at school at all, given the lack of specialist teachers and the limited number of hours in the school day – perhaps it would be better for schools to focus on mathematics instead, a subject with which Computer Science has much in common? It seems reasonable and timely, therefore, to ask ourselves now whether the subject called 'ICT' in schools should be 'shut down' or 'restarted' – particularly in the light of the 2011-12 review of the National Curriculum in England. It is unlikely to come as a surprise to readers of this report that we come down firmly on the side of a restart.

This report aims to analyse the status quo and to find ways that it can be improved upon. A primary route to improvement will be to displace some of the routine ICT activity with more creative, rigorous and challenging Computer Science. We have met 'sparkling' teachers who are clearly already capable of delivering Computer Science lessons in schools, but many others will find these proposals daunting. Head teachers should start by recognizing the importance of Computer Science to the future lives and careers of the pupils in their care, and take this into account when appointing teachers by looking for those with relevant training and/or experience. But we recognise that in most cases Computer Science will be taught by existing staff, and they will need help.

We aspire to an outcome where every primary school pupil has the opportunity to explore the creative side of Computing through activities such as writing computer programs (using a pupil-friendly programming environment such as Scratch). At secondary school every pupil should have the opportunity to work with microcontrollers and simple robotics, build web-based systems, and similar activities. We recognise that not all pupils will wish to seize these opportunities, but they should be able to do so if they do wish to.

In addition to curriculum opportunities to explore the creative side of Computing, we would like to see this taken further in extra-curricular activities such as computer clubs. These clubs would encourage motivated pupils to explore the creative side of Computing further, and universities and industry should get involved. Perhaps there is even a new role here for the BBC in encouraging and supporting creative Computing education in school and wider populations?

The UK has produced a galaxy of Computer Science stars from Alan Turing to Tim Berners-Lee – both Fellows of the Royal Society – and we want to be sure that the UK returns to the forefront of development in Information Technology and Computing. The scale of the challenge should not hold us back.

Steve Furber
January 2012

Executive summary

Background

This report is the outcome of a project initiated by the Royal Society in August 2010. The project was prompted by a high degree of concern, expressed in many quarters and documented in several earlier reports, about aspects of the current provision of education in Computing in UK schools. That such concern had been expressed by so many with such different perspectives – including in schools, in business and industry, and in universities – was indicative of a significant problem. The project was guided by an Advisory Group that brought together individuals and representatives with a wide range of professional interests and views, and it sought and achieved a good level of consensus.

The main findings and recommendations of the project are set out below. First, however, a word is needed on terminology. In this report, the term 'Computing' is used with a very broad sense. Computing is concerned both with computers and computer systems – how they work and how they are designed, constructed, and used – and with the underlying science of information and computation. The influence of Computing in shaping the world in which we now live has been profound, and it is hard to imagine that Computing will become less important in the future. It is argued in this report that it is essential for all school pupils to gain some familiarity with aspects of Computing and for there to be opportunities for pupils to develop their aptitudes in the subject, for their individual benefit and for the future prosperity of the nation.

Main findings

1. The current delivery of Computing education in many UK schools is highly unsatisfactory. Although existing curricula for Information and Communication Technology (ICT) are broad and allow scope for teachers to inspire pupils and help them develop interests in Computing, many pupils are not inspired by what they are taught and gain nothing beyond basic digital literacy skills such as how to use a word-processor or a database.

This is mainly because:

1.1 The current national curriculum in ICT can be very broadly interpreted and may be reduced to the lowest level where non specialist teachers have to deliver it;

1.2 there is a shortage of teachers who are able to teach beyond basic digital literacy;

1.3 there is a lack of continuing professional development for teachers of Computing;

1.4 features of school infrastructure inhibit effective teaching of Computing.

2. There is a need to improve understanding in schools of the nature and scope of Computing. In particular there needs to be recognition that Computer Science is a rigorous academic discipline of great importance to the future careers of many pupils. The status of Computing in schools needs to be recognised and raised by government and senior management in schools.

Terminology used in this report (see also Chapter 2)**:**

Computing

The broad subject area; roughly equivalent to what is called ICT in schools and IT in industry, as the term is generally used.

ICT

The school subject defined in the current National Curriculum.

Computer Science

The rigorous academic discipline, encompassing programming languages, data structures, algorithms, etc.

Information Technology

The use of computers, in industry, commerce, the arts and elsewhere, including aspects of IT systems architecture, human factors, project management, etc. (Note that this is narrower than the use in industry, which generally encompasses Computer Science as well.)

Digital literacy

The general ability to use computers. This will be written in lower case to emphasize that it is a set of skills rather than a subject in its own right.

3. Every child should have the opportunity to learn Computing at school, including exposure to Computer Science as a rigorous academic discipline.

4. There is a need for qualifications in aspects of Computing that are accessible at school level but are not currently taught. There is also a need for existing inappropriate assessment methods to be updated.

5. There is a need for augmentation and coordination of current Enhancement and Enrichment activities to support the study of Computing.

6. Uptake of Computing A-level is hindered by lack of demand from higher education institutions.

What needs to be done?

It is clear that over the 30 years since the introduction of the BBC Micro, Computing has grown enormously in importance and now underpins almost all areas of the modern world. Almost all citizens need a certain level of computer literacy to access online resources, which today are found in every walk of life. A substantial and increasing workforce earns its living in the IT and IT-related industries. A simple stroll down the carriage of any railway train will attest to the extraordinary use to which every citizen puts these devices.

This world enriched by information technology is, in part, a consequence of educational initiatives. In 1982 the BBC Micro itself was one aspect of a sustained drive to inform and educate the young. Ten years ago, in response to a skills crisis in industry, schools were equipped to teach ICT to all young people. The result is a generation at ease with the complex software used in business and able to pass on its knowledge to generations who would otherwise have missed out.

Surprisingly, despite the near-ubiquity of computer technology, there is now a dwindling interest in studying Computing at school.

To address these issues urgent and immediate action needs to be taken:

- The review of the National curriculum in England should be used as an opportunity to look at a radical overhaul of ICT in schools including rebranding and providing clarity on the different aspects of Computing currently lumped together under this heading.

- Targets should be set and monitored for the number of specialist Computing teachers. Training bursaries should be available to attract Computer Science graduates into teaching. Education Scotland should ensure that the entitlement of all learners to third-level outcomes in Computing Science is fully implemented.

- Government should set a minimum level of provision for continuing professional development (CPD) for Computing teachers, should seek support from business and industry to make that provision, and should ensure that the provision is well coordinated and deepens subject knowledge and subject-specific pedagogy.

- Providers of school infrastructure services should offer greater flexibility to schools to rebalance network security against requirements for effective teaching and learning in Computing. Suitable technical resources (robotics kits, etc) should also be made available.

- Information, guidance and positive incentives should be offered to heads of schools to enable them to appreciate the nature and scope of Computing and how problems described in this report can be addressed.

- A review of qualifications, curricula, and the means of delivering them should ensure that all pupils gain exposure to essential aspects of Computing and that those pupils with an aptitude for the subject are able to develop it to a higher level.

- Awarding organisations should review assessment methods for qualifications in Computing – such as documenting coursework with screenshots – to ensure that they are effective and do not have a negative impact on learning and teaching.

- A framework to support both non-formal learning in Computing and teachers of Computing should be established, to include after-school clubs, school speakers, and mentoring for teachers. In order to determine the focus of future investment, the effectiveness of different Enhancement and Enrichment activities in Computing should be assessed.

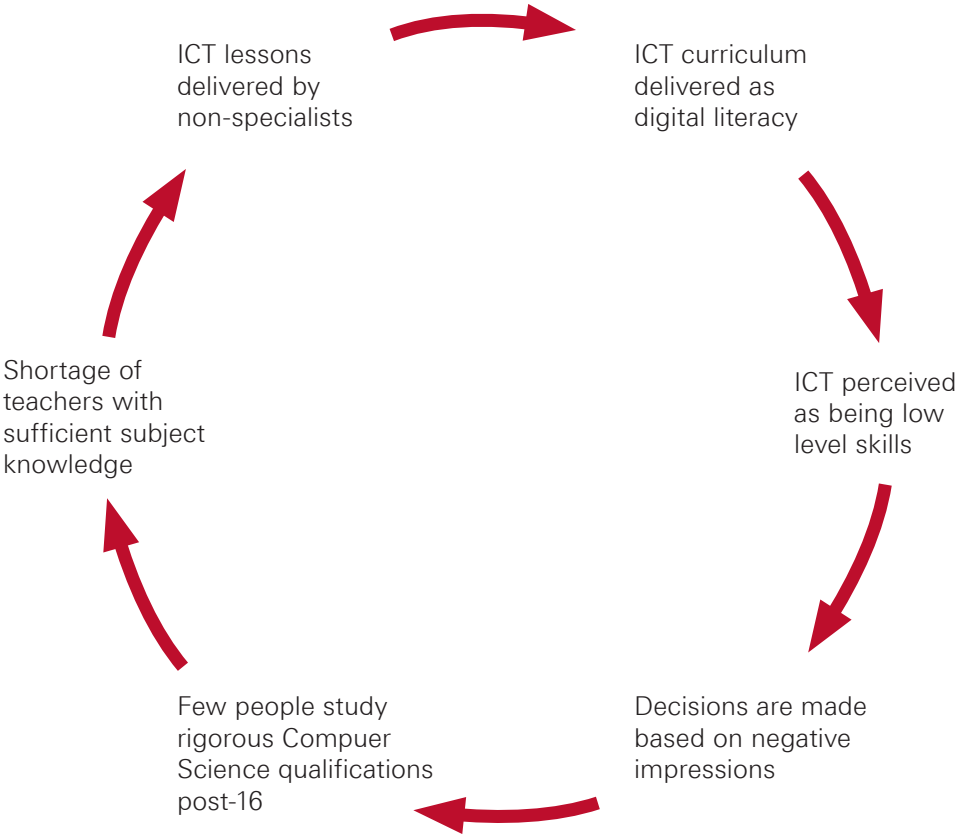
- Awarding organisations should develop rigorous Level 3 (A-level or equivalent) academic qualifications in Computer Science.

In order to progress the recommendations within this report a UK Forum should be formed for joint working and coordination between the many Computer Science and ICT bodies.

A nexus of inter-related factors reinforces the status quo

This cycle is driven by terminological confusion, and is connected to other issues such as access to Continuing Professional Development, the perceived quality of qualifications, HE entry requirements, the status of the subject amongst head teachers, and many others.

These issues interact so as to preserve the status quo. Interventions are required at more than one point to break the cycle.



Issues and recommendations

1. The current delivery of Computing education in many UK schools is highly unsatisfactory

1.1 The current National Curriculum in England lumps together a range of aspects of Computing including Computer Science, Information Technology and digital literacy under the heading 'ICT'.

A consequence is that Computer Science is often forgotten or ignored within the heading of ICT, resulting in teaching being biased towards 'how to use office software' rather than the knowledge that will form a foundation for the rest of a pupil's life. This has led to many people holding a very negative view of 'ICT', to the extent that terminological reform and careful disaggregation is required.

Fundamentally, industry, academe and teachers lack a consistent language within which to communicate business needs, careers advice and curriculum content to policy stakeholders including Government. Existing terminology gives rise to considerable confusion which can affect young people's subject choices and lead to poor policy-making.

Every section of the community appears to use different words in different ways. 'ICT' is an unusually problematic term because it has at least five separate meanings in the school context (see section 2.1).

The focus of this report is principally on the current, English, Welsh and Northern Ireland National Curriculum subject called ICT but with the existing terminology it is difficult to express this.

This confusing situation should not be allowed to continue.

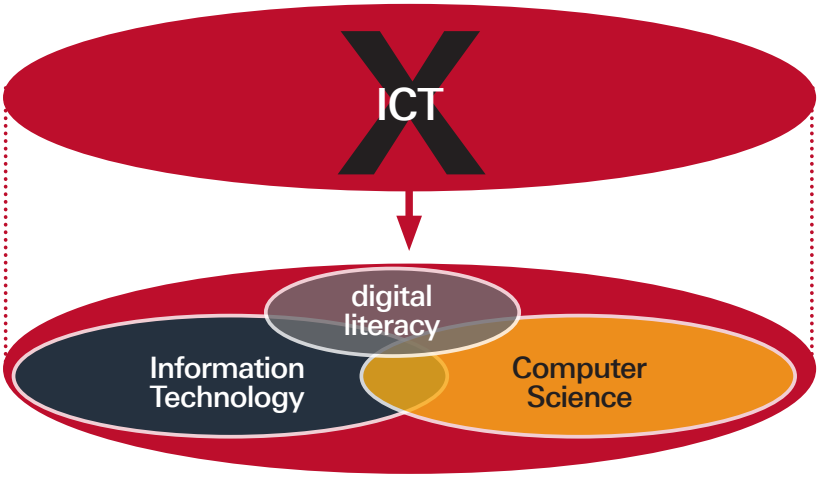
Recommendation 1 (see Chapter 2)
The term ICT as a brand should be reviewed and the possibility considered of disaggregating this into clearly defined areas such as digital literacy, Information Technology and Computer Science. There is an analogy here with how English is structured at school, with reading and writing (basic literacy), English Language (how the language works) and English Literature (how it is used).

The term 'ICT' should no longer be used as it has attracted too many negative connotations.

1.2 There is a shortage of specialist teachers able to teach Computing

There are simply not enough teachers with sufficient subject knowledge and understanding to deliver a rigorous Computer Science and Information Technology curriculum in every school at present. An action plan needs to be put in place to correct this, with a view to enabling all young people to have the opportunity to study Information Technology and Computer Science.

Suggested terminological reform



Recommendation 2 (see Chapter 7)
The government should set targets for the number of Computer Science and Information Technology specialist teachers, and monitor recruitment against these targets in order to allow all schools to deliver a rigorous curriculum. This should include providing training bursaries to attract suitably qualified graduates into teaching – for which industry funding could be sought.

Education Scotland should ensure that the declared entitlement of all learners to third-level outcomes in Computing Science is implemented in all schools for all learners using appropriately qualified teachers.

1.3 There is a lack of continuing professional development (CPD) for teachers

There is a lack of support for CPD that deepens subject knowledge and subject-specific pedagogy in this area, particularly in Computer Science. This needs to be addressed – it is important that teachers have access to good quality CPD, particularly given the lack of specialist teachers. This will be essential to support a new curriculum in schools.

Recommendation 3 (see Chapter 7)
Government departments with responsibility for Education in the UK should seek industry support to extend existing funding in this area, and should ensure that there is coordination of CPD provision for Computer Science and Information Technology teachers that deepens subject knowledge and subject-specific pedagogy.

Government should set a minimum level of provision for subject-specific CPD for Computing teachers, should seek support from business and industry to make that provision, and should ensure that the provision is well coordinated and deepens subject knowledge and subject specific pedagogy.

1.4 School infrastructure is holding back good teaching

Important aspects of Computer Science and Information Technology teaching and learning are being compromised by the need to maintain network security – an analogue to health and safety myths holding back practical science.

Recommendation 4 (see Chapter 7)
School infrastructure service providers, working with others, should prepare a set of off-the-shelf strategies for balancing network security against the need to enable good teaching and learning in Computer Science and Information Technology, and should encourage schools to discuss and adopt them with their service providers. Such a "Guide to Best Practice" should be used by schools and local authorities as part of any tendering process for outsourced service provision.

1.5 Technical teaching resources are often inadequate

Although some schools are already making exemplary use of microcontrollers and robotics kits alongside PCs, it is clear that many are not yet equipped to do so.

Recommendation 5 (see Chapter 7)
Suitable technical resources should be available in all schools to support the teaching of Computer Science and Information technology. These could include pupil-friendly programming environments such as Scratch, educational microcontroller kits such as PICAXE and Arduino, and robot kits such as Lego Mindstorms.

2. Computer Science is a rigorous academic discipline and needs to be recognised as such in schools

Computer Science is a rigorous academic discipline, distinct from, but on an equal footing with, other disciplines such as mathematics, physics, chemistry, geography or history. Like mathematics, Computer Science underpins a huge range of subjects, and has concepts and ways of working that do not change quickly over time, including programming, algorithms and data structures. Our definitions of these terms are given on page 5.

Mirroring the expansion of computers into all areas of modern life, the academic discipline of Computer Science has advanced and has introduced new, important ways to view and understand the world in which we live. "Computational thinking" offers insightful ways to view how information operates in many natural and engineered systems.

Computer Science is also highly creative. This may be self-evident in the case of computer games, electronic art and computer-generated music, but these examples from the "creative" industries perhaps conceal the fact that writing any computer program involves creativity in the virtual universe behind the screen, and the fact that this is not widely realised or recognised reflects a need to communicate the intrinsic beauty and creativity of the discipline.

The time has come for Computer Science to be recognised in schools as a subject in its own right.

3. Every child should have the opportunity to learn Computing at school

We believe that:

- Every child should be expected to be 'digitally literate' by the end of compulsory education, in the same way that every child is expected to be able to read and write.
- Every child should have the opportunity to learn concepts and principles from Computing (including Computer Science and Information Technology) from the beginning of primary education onwards, and by age 14 should be able to choose to study towards a recognised qualification in these areas.
- Pupils should be exposed to, and should have the option to take further, topics such as: understanding of the internet and the design of web-based systems; the application of computers in society, business, the arts, science and engineering; computer programming, data organisation and the design of computers; and the underlying principles of computing.

These principles should apply across the UK. We make the following recommendation to achieve this in England.

Recommendation 6 (see Chapter 4)
The Department for Education should remedy the current situation, where good schools are dis-incentivised from teaching Computer Science, by reforming and rebranding the current ICT curriculum in England. Schemes of work should be established for ages 5 – 14 across the range of Computing aspects, e.g. digital literacy (the analogue to being able to read and write), Information Technology, and Computer Science.

These should be constructed to be implementable in a variety of ways, including a cross-curricular approach for digital literacy at primary and early secondary school. Schools may prefer not to impose a timetable or separately staff these elements at this age, but the existence of separately-defined learning experiences will ensure that each strand is always properly developed – unlike at present.

A timetable distinction should then be in place from the age of 14, allowing pupils to make a well-informed choice to study for recognised qualifications in Information Technology and/or Computer Science.

Given the lack of specialist teachers, we recommend that only the teaching of digital literacy is made statutory at this point. However, the long-term aim should be to move to a situation where there are sufficient specialist teachers to enable all young people to study Information Technology and Computer Science at school. Accordingly, the Government should put in place an action plan to achieve this.

The schools inspectorates should monitor the implementation of this change to ensure that the problems of the current curriculum are not replicated.

This approach aims to ensure that pupils are equipped with the basic skills they need at an early age but are not subjected to repeating things they already know. It provides a route for specialisation at the age of 14, and maintains a separation between basic level skills and the rigorous discipline of Computer Science. It also mirrors the existing science curriculum – with minimal distinction between strands at the early ages and greater differentiation at secondary school.

4. There is a need for qualifications in aspects of Computing that are accessible at school level but are not currently taught. There is also a need for existing inappropriate assessment methods to be updated.

The range of ICT and Computer Science-related qualifications at Level 2 in England, Wales, and Northern Ireland is overly diverse and confusing. Many of these qualifications do not appear to provide what employers and HE are looking for; others lack the currency of GCSEs and A-levels. The progression routes (e.g. from level 2 to level 3, or to employment or HE) are poorly defined.

The number of people entering ICT and Computing at GCSE and A-level has declined significantly in recent years. There is a similar trend in Scottish Highers and Advanced Highers.

Conversely, there has been a significant increase in the numbers studying OCR Nationals and other vocational ICT qualifications; however, perception of these is mixed and there has clearly been a shift away from academic Computer Science qualifications.

Recommendation 7 (see Chapter 5)
In order to redress the imbalance between academic and vocational qualifications in this area – and to ensure that all qualifications are of value to those who take them – the departments for education across the UK should encourage Awarding Organisations to review their current provision and develop Key Stage 4 (KS4) qualifications in Computer Science in consultation with the UK Forum (see recommendation 11), universities and employers.

Awarding Organisations across the UK should review and revise the titles and content of all new and existing qualifications in this area to match the disaggregation described above (e.g. Computer Science, Information Technology and digital literacy).

Assessment methods that rely on taking screenshots to document coursework (rather than take advantage of more modern submission methods) are a contributor to the negative perception of ICT.

Recommendation 8 (see Chapter 5)
The UK Forum (see recommendation 11) should advise Awarding Organisations on appropriate assessment methods for qualifications in digital literacy, Information Technology and Computer Science.

5. Enhancement and Enrichment (E&E) activities are needed to support the curriculum

There are many successful science, engineering and mathematics E&E activities in existence but there is lack of understanding in schools of what opportunities are available; rather than introducing further new schemes the existing activities need to be augmented, with better coordination between them to avoid fragmentation.

Many out-of-school STEM club schemes exist and have been shown to be effective. With sufficient support these could be extended to complement a Computer Science curriculum, thereby raising awareness of the subject and inclination towards further study.

Recommendation 9 (see Chapter 4)
The UK Forum (see recommendation 11) should put in place a framework to support non-formal learning in Computer Science and to support teachers. Considerations include after-school clubs, school speakers and mentoring for teachers in developing their subject knowledge. Bodies such as STEMNET will have a role to play in implementing this.

To inform the focus of investment in non-formal learning in Computing, the UK Forum should also look at establishing a rigorous evidence base for the effectiveness and value of various Computer Science E&E activities. Affordability will also be a relevant consideration.

6. Uptake of Computing A-level is hindered by a lack of demand from HE

Few HE departments appear to hold Computing A-level in high esteem and development of rigorous high-quality post-16 courses is required with the label 'Computer Science'.

There is a follow-through effect in numbers studying Computer Science courses in HE, which suffers from a high first-year attrition rate – possibly as a result of students arriving without a clear understanding of what Computer Science is.

Recommendation 10 (see Chapter 6)
Awarding Organisations should consult with the UK Forum (see recommendation 11 in Chapter 2) and HE departments to develop rigorous Level 3 academic qualifications in Computer Science.

How can these recommendations be taken forward?

A broad range of professional bodies, subject associations, academies and learned societies have an interest in this area, arising from the underpinning nature of Computer Science and the all-pervading nature of Information Technology in the modern world. Meeting the challenges of this report is a shared responsibility, and coordination between these bodies will be essential to provide a clear voice to government and to carry forward the recommendations in this report.

Many institutes and societies associated with other areas of science, engineering and mathematics such as the Royal Society of Chemistry, the Institute of Physics and the Society of Biology, have their origins in a community of many small organisations, and to some extent the process of subject division and recombination is a natural part of the evolution of a discipline. The bodies working in this area must now work closely together if the desired change is to be achieved.

Recommendation 11 (see Chapter 2)
The Computing community should establish a lasting UK Forum for joint working and coordination between the many Computing bodies, in order to progress the recommendations within this report. The Forum should provide regular progress reports on the implementation of the recommendations.

Summary

The UK has a proud history of contributions to Computing and especially to the discipline of Computer Science, but current terminology, curricula and qualifications are holding us back from being a nation of technology creators. Whilst a lot has been achieved in establishing a digitally literate population, our aspirations should not stop there. There are many barriers to progress, and a joined up approach is required. This report sets out a positive way forward for the community.

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