Nuffield Foundation

Report focus
This report examines how digital technologies are used in schools to enhance learning, and identifies research questions to inform better practice and policy.

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Growing up digital: What do we really need to know about educating the digital generation?

About the author

Professor Angela McFarlane is a successful author and international authority on technology enhanced learning and teacher development.

About the Nuffield Foundation

The Nuffield Foundation is an independent charitable trust with a mission to advance social well-being. Our aim is to improve people's lives, and their ability to participate in society, by understanding the social and economic factors that affect their chances in life.

We fund research that informs social policy, primarily in Education, Welfare, and Justice. We also fund student programmes – Nuffield Research Placements and Q-Step – to enable young people to develop skills and confidence in quantitative and scientific methods.

We have established the Ada Lovelace Institute, an independent research and deliberative body with a mission to ensure data and AI work for people and society, and we are the founder and co-funder of the Nuffield Council on Bioethics.

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Foreword

The rapid growth in the use of digital technologies has had a transformational effect on our economy and society. Such technologies are now fundamental for large swathes of the workforce and people's lives are increasingly digitalised and connected, with computers and algorithms mediating many daily activities. The acquisition and use of digital skills underpin participation in the labour market, and in consumer, social and civic life.

How has the education system responded to this? The requirement for young people to develop digital competency and fluency drove changes to the curriculum introduced in England from 2014, with Computing becoming mandatory up to age 16. Concerns have been raised about the implementation of this major curriculum reform, including a 2017 Royal Society report that highlighted challenges around the capacity of the teaching workforce to deliver on the aspirations of reforms. As such, the recent establishment of a National Centre for Computing Education, focused on improving teaching across English primary and secondary schools, is a welcome development.

We must also consider the efficacy of information and communication technologies for teaching and learning. As the Education Endowment Foundation (2019) and others have found, putting technology into schools does not in itself boost young people's learning or enhance the skills of teachers in improving learning outcomes. The integration of technology with pedagogical approaches and a clear understanding of the purpose of technology in the classroom are essential.

Overall, despite all the activity and investment, there is no shared view of what the digital education agenda is aiming to achieve and what the priorities should be for policy-makers and practitioners. In a context of relatively rapid change in what is taught, how it is taught and why, it is particularly difficult to ensure that policy and practice are informed by high quality evidence.

We commissioned this report to clear the ground, assess the existing evidence base, and identify key questions and issues for future research. Professor Angela McFarlane's wide-ranging experience at the interface between policy, practice and research made her ideally placed to undertake this exercise. In producing this report, she has consulted closely with the Foundation and a range of other stakeholders with relevant expertise.

The report provides a significant contribution to the debate around computing education and digital skills, exposing challenges for a field that appears to want to move rapidly from problems to solutions. It also provides pertinent guidance for those seeking to improve the evidence base around the cornerstones of educational reform: curriculum, assessment, pedagogy and teacher supply and development.

The use and impact of digital technologies is a priority for the Nuffield Foundation in our work to advance social well-being. We hope this report will act as a stimulus for well-directed and high-quality research proposals for the Foundation and other funders, that can improve the evidence base and inform policy and practice on education in the digital society.

Josh Hillman

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Executive summary

This report seeks to examine the current evidence base and explore the apparent tension between technology as an object of study and technology as a teaching and learning aid. The purpose is to inform a future research agenda and suggest where further or new evidence might better support an informed view of curriculum and pedagogy to prepare school pupils for the world they live in and school leavers for the world they will shape.

The consequences and implications of the digital revolution for education have prompted much debate nationally and internationally among policy makers and educators. A shared conclusion is that the *status quo* is unacceptable.

In 2015 the House of Lords Digital Skills Committee produced a report, *Make or Break: the UK's Digital Future*, which considered the relationship between digital technologies and education and in particular, the school curriculum. The Royal Society had earlier considered the same issues, in its report entitled *Shut down or restart?* (2012*)* with similar conclusions: young people were not learning enough about digital technologies or their appropriate use.

At the same time research evidence suggests technology use has limited impact on learning. Moreover, the positive impact of these interventions on learning outcomes are no greater than any other, arguably less expensive, innovations and considerably less than some.

The latest Department for Education (DfE) strategy, *Realising the potential of technology in education* (2019) emphasises the use of technology for efficiencies in administration and teaching internet safety, and to support learning where there is evidence of impact. Similarly, the Education Endowment Foundation (EEF) guidance on use of technology in education (2019) is cautious in its advice with an emphasis on using technology only where there is a well understood link to teaching objectives.

It would seem that the evidence base supports a coherent argument that schools should be teaching about digital technology as a subject of study. There is less data to support the use of technology to enhance teaching and learning more broadly.

The points of consensus which emerge from the current and the most recent reviews are these:

- Putting computers into schools is no guarantee that there will be a positive impact on learning outcomes as measured in high stakes assessment or the development of digital literacy.
- How digital technologies are used is as important as whether they are used.
- We don't have a shared picture of what effective digital pedagogies look like.
- Teachers may not have opportunities to develop the skills they need to make effective use of technology.
- The current use and knowledge of computer-based technology in schools and at home is leaving many young people vulnerable to adverse influences and unprepared for the world of work.

These findings have significant implications for:

- Curriculum.
- Pedagogy.
- Teacher development.
- Assessment.

This report considers each of these issues, with comments on current practice, the evidence base (where it exists), and suggestions for the future research agenda.

Underpinning all of these issues is a fundamental question of what it means to be a successful learner and how the use and knowledge of computer-based technology can both contribute to and evidence that success. Currently almost all research uses some form of test - often high stakes summative scores - as a measure of impact on learning. Since the syllabuses on which these tests are based rarely include elements of technology supported pedagogy, it is perhaps no surprise that any correlations are weak. This is further complicated when we consider the importance of collaboration and creativity, both of which can be facilitated through use of particular digital technologies, which are seen as vitally important to future economic success for individuals and nations. Neither of these skill sets feature significantly on national testing frameworks at school level. This is in no small measure because they are hard to quantify. How can these skills be recognised and accredited? Can the contribution of the individual be separated from that of the pair, or team?

The current 5 to 16 curriculum in the UK nations mandates the teaching of Computing. In 2013, ICT was replaced by Computing to make the subject more robust by adding computer science. The aspiration is that young people will emerge from this experience well versed in 'computational thinking', ready to be effective users and in some cases, developers of digital technologies.

There is scope for a study to look at the affective outcomes of this curriculum both now and in the long term. How are attitudes, as well as aptitudes, being influenced by this experience – and what factors in particular are driving students to, or away from computer science? There is a recognised interplay with the experience of learning maths, and the preparedness of teachers to teach this curriculum is likely to be a variable here.

Any research programme will need to take account of the need to gather data from established practice, not simply at the implementation stage where technical glitches and the halo effect can both skew findings significantly. Moreover, when considering impact on outcomes, particularly those which influence longer term choices, there is a need for longitudinal studies as well as, where possible, retrospective ones.

A focused and well-designed programme could help to produce a more robust evidence base on the impact of educational technology. The outcomes of this could then inform the debate on how best to prepare school students for a future which is increasingly digital.

Section 1: What do we really know about educating the digital generation?

Why this report?

The role of digital technologies in the classroom remains a contested issue. Currently there is widespread popular debate on children and young people's use of social media and its potential link to mental ill-health. As the device most used by young people to access digital media, mobile phones are of particular interest, with the seductive nature and constant presence of these devices leading to calls for their use to be banned in schools. Some headteachers have already taken a lead. Yet techno-evangelists liken this to asking short sighted students to leave their spectacles at the school gate, so integrated into daily life is the use of a connected communication device.

At the same time, national and international commentators identify a lack of digital skills among school leavers and claim this leaves them ill-suited to pursue further study or join the workforce, and vulnerable to exploitation. A lack of awareness of the power of big data – such as the digital footprint created by every use and user – and its potential use and mis-use by AI systems, is believed to considerably increase the threat to the naïve user (The Institute for Ethical AI in Education, 2018).

Amidst such different views of the role and potential of digital technologies in the lives of children and young people, this report looks to evidence from the existing research base to inform effective policies and practice. By giving an overview of the research evidence, in the context of changing policy, the report seeks to answer the question, "What effect does the use of digital technology have on learning?".

The current review

The context of this report is compulsory schooling in the UK, with reference to international sources where these are relevant. This report focuses on the evidence base that exists to date from major studies and research programmes and reviews, nationally and internationally. The purpose is to identify where gaps in our understanding could be bridged by targeted, future research. In particular, areas where research is feasible and affordable are highlighted.

The evidence base has been examined relative to four particular variables which have consistently been shown to be important in improving attainment in school systems; curriculum, pedagogy, teacher development and assessment. The curriculum element considers the place of digital technologies as the subject of study, e.g. in computer programming, as well as their use as a tool per se and in the context of learning other subjects. The report will not focus in depth on issues of physical access to technology other than to record the important factors which must be addressed to support integrated and assimilated use. One conclusion the current available evidence does support is that access to reliable and robust hardware, software and high-speed connectivity is a necessary but not sufficient condition for effective use to support teaching and learning. As Higgins et al. point out, many studies collect data during the early stages of implementation and the effects observed may not sustain over time (Higgins et al., 2012). Things might have looked very different later in the implementation, and there is no way of knowing if the implementation beds in or is abandoned.

Challenges

Volume and quality

With such a long history and relatively significant investment in implementation and research into this area by governments and research councils in the UK and major corporations and NGOs internationally, a lot of evidence has, unsurprisingly, been generated. However, individual studies are often problematic. Factors such as size of the cohort, length of the study, maturity and detail of the intervention can undermine the generalisable nature of the findings. Nevertheless, recurring results and consensus are likely to be significant where they occur.

Digital technologies are far from being a single variable. Moreover, how they are used is as important as what is used. Comparing studies, or aggregating them, may be misleading as a result. Nonetheless Higgins et al. (2012) identified some 48 meta-analyses of the impact of learning technologies on pupil outcomes which were carried out over a 32-year period. Given the spending on, and profile of, technology programmes in schools it is perhaps surprising there have not been more.

Pace of change

Technology changes rapidly. There is a temptation to assume that evidence loses its currency equally rapidly. Education practices, and the human brain, change much more slowly however and it is important to recognise persistent factors in the complex ecology of digital technology in the learning space. Policy and curriculum also change frequently. As a result, learners' experience over time can be hard to compare. A six-year-old child today has a different experience from that which an 18-year-old had at the same stage. That said, the overall finding that interventions using digital technologies produce, at best, small positive gains in learning outcomes remains remarkably consistent.

Access to sources

The type of major studies which form the backbone of this report are widely available via the Internet or in books. Individual journal papers have not been used extensively. Despite the quality assurance that peer review affords such sources, they report on small scale studies for the most part and due to space constraints record insufficient detail of the interventions studied to be sure if they are in fact comparable. Moreover, the resource and time available for the current report did not allow for a comprehensive review of the thousands of sources available. Rather this report draws on the most recent reviews and meta-analyses in the areas of computer science and technology use in education, informed by discussions with key influencers in these fields in the UK, US and Chile where some of the most innovative examples of computer-based assessment have been pioneered.

The sources used are predominantly published meta-analyses and reports from major stakeholders such as the Organisation for Economic Cooperation and Development

(OECD), the Royal Society, Education Endowment Foundation (EEF) and the Department for Education (DfE). The aim was to give a sense of the major themes which have emerged and persisted over the 50 years that computers have been in use in schools, and to consider that history in a contemporary context. The objective was to discover if there are clear gaps in the evidence base and thus to inform thinking about a future research agenda.[1]

The context

It is now something of a cliché that pupils in the school system are growing up in a world that has been affected in almost every sphere by the development and adoption of digital information and communication systems. They will leave school to enter a world that will continue to change and be changed by digital technologies. Machine learning, artificial intelligence and 'big data' are the latest predicted revolutionary technologies, which may change our entire notion of 'work' and 'job'. Those currently at school already inhabit a society where digital technology means that personal interactions and expressions of identity are entirely different from those experienced by their teachers and parents. Whichever sphere of work they enter, it is unlikely to be entirely untouched or unchanged by digital technologies of one kind or another and they will almost certainly be users and/or architects of new and changing applications of computer technologies throughout their lives. The degree of penetration of computing technologies, their complexity and the rate at which they evolve all present urgent questions of how best to prepare young people to be competent and successful, socially and economically in the present and in a future we can only imagine (Luckin, 2018).

The consequences and implications of the digital revolution for education have prompted much debate nationally and internationally among policy makers and educators. A shared conclusion is that the status quo is unacceptable. In 2015 the House of Lords Digital Skills Committee produced a report, *Make or Break: the UK's Digital Future*, which considered the relationship between digital technologies and education and in particular, the school curriculum. The Royal Society had earlier considered the same issues, in its report entitled *Shut down or restart?* (2012) with similar conclusions: young people were not learning enough about digital technologies or their appropriate use.

The latest Department for Education strategy, *Realising the potential of technology in education* (2019) has an emphasis on use of technology for efficiencies in administration and teaching internet safety, with use to support learning where there is evidence of impact. Similarly, the Education Endowment Foundation guidance on use of technology in education (2019) is cautious in its advice with an emphasis on use where there is a well understood link to teaching objectives.

The importance for education of the changes in the way we communicate and access information, fuelled by a digital revolution, was underlined in 2013 when the OECD included

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[1] The first review of these sources was carried out in 2018. In February 2019, the Nuffield Foundation hosted an invitational expert seminar (see Appendix 1 for the attendees and output of this event). In April 2019 the EEF published a guidance report based on an update to its review (Higgins et al., 2012) of research on digital technologies and learning and the DfE published a new strategy: Realising the potential of technology in education: A strategy for education providers and the technology industry. A final edit of the report was undertaken in April 2019 to take account of these three important sources.

additional items in the Programme for International Assessment (PISA) tests to assess the ability to use information and navigate on-screen sources competently. This long running international comparative study is taken as a proxy for the overall performance of national school systems in terms of their effectiveness in preparing children for economic and social success. It is a comparison that attracts ministerial and media attention, and whilst there are elements of the programme design and implementation which are contested, they provide some of the best comparative evidence available and carry weight at policy level. As an indicator of the direction of travel, collaborative problem solving was introduced in 2015. Only 8% of students scored highly in these items across the globe (OECD, 2017), so the UK is not uniquely badly placed in this respect. This is also interesting given that collaborative learning is one of the areas where there is some evidence that use of computers can have a positive impact (Higgins et al., 2012). Collaboration is also known to increase the chances of learning taking place more generally (see Baume and Scanlon, 2018).

Taken together, national and international policy discourse as set out in the reports cited above, is sending the message that economic prosperity is dependent on a workforce skilled in digital practices including information handling and problem solving and equipped with technical skills such as coding. Moreover, schools have a key role to play in addressing the current skills gap which too often sees those leaving education ill-equipped for a digitalised work place and predicted shortages in all STEM (science, technology, engineering and mathematics) professions in particular. The UK declined to take part in the OECD (2017) study for the relevant measures of digital competence, so there is no data to support a direct comparison with our economic partners or competitors in these areas. However, both the House of Lords and Royal Society papers promote the view that we have not been educating children and young people sufficiently well in matters digital. The Royal Society (2017) view was informed by a significant body of desk and field research.

The OECD (2017) concludes from its analysis of the 2015 trial and the wider PISA results, that basic literacy and numeracy remain vital to the development of digital competence and may in the long run be more important than general digital experience – learners with more out of school screen time did not achieve the highest test scores in digital information navigation. This rather undermines the notion of the Digital Native who intuitively uses digital technologies effectively simply because they were born into a world where such technologies already existed. This is of little comfort however since the UK, along with a majority of European nations and the US, is sliding down the international league tables in measures of literacy and numeracy. It does however raise interesting questions as to how to design a curriculum which best prepares children and young people to enter the workforce, where the focus of that curriculum should lie, and what role the out of school use of digital technology plays.

A brief history

The potential relationship between digital technologies in schools and economic growth has been recognised in England and Wales since the early 1970s when Kenneth Baker (later Lord Baker), as Minister for Trade and Industry, funded the first Microelectronics Project (MEP) in schools. Since then there have been nearly 50 years of investment and development of programmes to put hardware and software into primary and secondary schools, with a less well funded parallel programme in further education colleges. The UK education technology industry has a global reputation, widely promoted by the British Education Suppliers Association (BESA) with major trade shows first in the UK and now internationally. Government agencies to support effective supply and use of these technologies to education were founded and well-funded for some 40 years. Over that time there were very significant investments in trials of leading-edge technologies in schools, usually followed by large scale roll out across the nations of the UK. Less frequently, budgets were made available for software. Very occasionally, there were programmes to provide training for teachers in the use of technology and/or software. Throughout, the budgets and programmes were overseen if not driven by a dedicated government agency. The overall investment was recognised as among the largest of any OECD country, although, perhaps inevitably, there was some debate over the wisdom of where and how the monies were spent.

Then in 2010, a new government took the decision to ‘downsize’ Whitehall. The current government agency, the British Education, Communications and Technology Agency (Becta), was closed overnight. Funding for schools was de-regulated and the decision whether to invest in technology was deferred to schools. The policy was justified by the absence of any substantial evidence that the investment to date had in fact contributed in any way to improvements in school performance as measured through high stakes assessment results, i.e. the summative tests at key transition points in education. In the UK these include Key Stage tests, GCSE and post 16 examinations such as A levels. Despite the wealth of opinion, analysis and theory advocating a link between computer use and effective education, the data supporting this link in practice, from nearly five decades of implementation and evaluation, remains elusive (Higgins et al., 2012; EEF, 2019).

Whilst personal ownership of digital devices by school age pupils continues to grow and starts at an ever earlier age, current use in schools in the UK appears to be less widespread. Even though Computing has been a mandatory subject in the UK countries since 2014 recent data show that some 40% of children experience only an hour a week of computer use in the curriculum (Royal Society, 2017). This suggests there is likely to be little use of digital technologies in subjects other than computing and use cannot be described as widespread or embedded. An Ofsted review of evidence from school inspection reports looking at information and communication technology from 2008 to 2011 found a similar pattern suggesting that this mode of use in schools is well established and ubiquitous use of technology across the curriculum has always been an exception (Ofsted, 2011). The reasons for this are many and are likely to include access to suitable infrastructure and devices. That said, there is no recent publicly available data on equipment and infrastructure levels in schools and colleges since the annual survey (by the variously titled government department responsible for education) ceased long ago and the UK did not take part in the latest OECD survey in 2012.

The only source currently is the industry survey of computer presence in schools conducted by BESA which in 2013 showed a reduction in the computer to pupil ratio of machines less than 5 years old for the first time (BESA, 2013). By 2017 the same source showed a slowing of new purchases and some third of all computers now in schools classed as ineffective. (Private communication of data published to BESA members in autumn 2017). The 2019 DfE’s *Realising the potential of technology in education* relies on the BESA report of 2018 for its statistics on access and barriers to use. It recognises access to fast broadband as a key barrier to use and promises action to address this in the school sector.

Machines alone are not enough

Access to machines may close the first element of the digital divide, but it is no guarantee of mastery or effective use. Perhaps the best evidence of this comes from the One Laptop per Child (OLPC) project that supplied thousands of specially designed computers to children in developing countries assuming they would teach themselves to code, develop applications and boost their learning much in the style of the original Logo vision.

Unfortunately, having spent millions of dollars of the education budget from some of the poorest countries in the world, standardised test scores remained stubbornly unaffected. However, there was some evidence from Peru that learners had improved their cognitive skills and were more effective learners (e.g. Cristia et al., 2012). This highlights a persistent and long running tension in the education technology debate – enthusiasts are interested in the ability to develop digital literacy and to generate personal knowledge, policy makers' judge impact through the outcomes on standardised tests. But it seems neither is finding the outcome they seek:

> Schools have yet to take advantage of the potential of technology in the classroom to tackle the digital divide and give every student the skills they need in today's connected world, according to the first OECD PISA assessment of digital skills. *Students, Computers and Learning: Making the connection* says that even countries which have invested heavily in information and communication technologies (ICT) for education have seen no noticeable improvement in their performances in PISA results for reading, mathematics or science.
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> OECD, 2015a

There are growing concerns that a lack of digital literacy is leaving young people ill-prepared to live in a digital society with all its promise and threats. The consequences of this failure to develop sufficient digital literacy are both social and economic. There is some evidence that exposure to pornography online is adversely influencing young people's understanding of sex within a healthy relationship (Horvath et al., 2013) and that the constant contact, comment and comparison which is the currency of social media is a factor in increased mental ill health in young people (e.g. Schurgin O'Keefe and Clarke-Pearson, 2011). Girls seem to be particularly affected by these social effects.

All learners from disadvantaged backgrounds suffer potential economic disadvantage as they remain under-represented in STEM generally and a range of potentially well-paid jobs are inaccessible to them. This has consequences for the economic success of individuals and the nation as the numbers overall entering a STEM career pathway suggest we will face an increasing shortfall in qualified scientists and engineers, including in digital industries.

The big picture

So, we have a complex picture in which a few things seem to be irrefutable from the evidence base:

- Putting computers into schools is no guarantee that there will be a positive impact on learning outcomes as measured in high stakes assessment or the development of digital literacy.
- How digital technologies are used is as important as whether they are used;
- We don't have a shared picture of what effective digital pedagogies look like.
- Teachers may not have opportunities to develop the skills they need to make effective use of technology
- The current situation in schools and homes is leaving many young people vulnerable to adverse influences and unprepared for the world of work.

Section 2: Taking a closer look

Despite a body of evidence stretching back over five decades, the evidence base for the impact of computer use in schools on student achievement remains underwhelming. It is also very varied. Small scale studies where individual teachers achieve outstanding results using computers continue to emerge and have done so for many years. Larger studies are rarer. Meta-analyses are useful, and Higgins et al. (2012) drew on some 45 conducted over 22 years up to 2012. The broad findings were:

- Collaborative use of technology (in pairs or small groups) is usually more effective than individual use, though some pupils, especially younger children, may need guidance in how to collaborate effectively and responsibly.
- Technology can be powerful as a short but focused intervention to improve learning, particularly when there is regular and frequent use (about three times a week) over the course of about a term (five to 10 weeks). Sustained use over a longer period is usually less effective at improving this kind of boost to attainment.
- Remedial and tutorial use of technology can be particularly practical for lower attaining pupils, those with special educational needs or those from disadvantaged backgrounds, in providing intensive support to enable them to catch up with their peers.
- In researched interventions, technology is best used as a supplement to normal teaching rather than as a replacement for it. This suggests some caution in the way in which technology is adopted or embedded in schools.
- Tested gains in attainment tend to be greater in mathematics and science (compared with literacy for example) though this is also a more general finding in meta-analyses and may be at least partly an artefact of the measurement process. In literacy the impact tends to be greater in writing interventions compared with reading or spelling.
- At least a full day's training or on-going professional inquiry-based approaches to support the introduction of new technology appear the most successful. The implication is that such support should go beyond the teaching of skills in technology and focus on the successful pedagogical use of technology to support teaching and learning aims.

The guidance report Using Digital Technology to Improve Learning (EEF, 2019) is based on an update to the Higgins et al., review. It makes four recommendations:

- Consider how technology is going to improve teaching and learning before introducing it.
- Technology can be used to improve the quality of explanations and modelling.
- Technology offers ways to improve the impact of pupil practice.
- Technology can play a role in improving assessment and feedback.

These recommendations suggest that research since 2012 provides some additional evidence into specific use (e.g. the third bullet refers to practice as in drill and repetition) but few new insights. Moreover, the fourth recommendation on assessment makes it clear that this only works where teachers understand how to use the performance data effectively to feed back into teaching.

In looking for evidence of the impact of technology on learning it is important to identify what, who, why and when that technology is being used to make any clear sense of the findings. It is vital also to be clear what 'impact' looks like.

The what

Clearly the type of computer use and the context of use are highly significant variables, but no shared typography currently exists either for the technologies or their areas of potential. As long ago as 2000, the current author, working for Becta, led a wide-ranging but unpublished review of evidence from seven bibliographic databases which looked at pupil attainment, SEN and inclusion, extension work and homework, behaviour including motivation and classroom and school management. At the time these were all believed to be areas of promise. Individual variation was very apparent in the data and is also clear from the large scale and longitudinal study, ImpaCT2, (Harrison et al. 2002) the largest such study in the UK to date. In the absence of agreed definitions of types of use, each report and indeed author, resorts to their own. There is therefore inevitably a degree of subjectivity when implementations are compared or collated.

The who

Technology is used most effectively by teachers who understand how and what to use to best support their teaching. This assumes they have access to that technology, which according to the available data, is not the case for most teachers.

Evaluations by the EEF and the most recent review of the evidence of factors affecting teaching quality (Coe et al. 2014) do not support the case for investment in digital technology as a means to improve teaching or overall outcomes or support disadvantaged learners. Indeed, the Coe et al. review makes a strong case for sound subject knowledge as the factor affecting teaching effectiveness for which there is the strongest evidence base. This chimes with a vocal and politically popular faction among teachers in England currently who call for a focus on teaching of subject matter, question the value and even the existence of '21st Century skills' and call for a close control of mobile phones in the classroom (e.g. Bennett, 2017). Unfortunately, recent data published by the Wellcome Trust (2017) shows that subject specific CPD is the rarest form of development teachers' experience.

Where learning outcomes are measured through test results, it seems there is a case for teachers with strong subject knowledge and the skills to inspire and communicate that knowledge whilst the case for teachers to also use technology in their teaching remains weak. However, where the outcomes of learning are viewed through the lens of employability or preparation for further study, the conclusions on the skill set of an effective teacher might be more extensive. Studies looking at teaching effectiveness through that filter do not so far exist.

The why and when

There are those who advocate for the inclusion of particular types of technology use in the curriculum from as early as age five, as preparation for life beyond school, whether as informed citizens, effective knowledge workers or computer scientists or software engineers. There are also those who advocate computer use for education as essential for those born into a digital world and for whom everything is therefore very different. Arguments promoting the role of digital technology in schools along these lines come largely from an ideological perspective rather than an evidence base (e.g. Prensky, 2012; Gee, 2003).

The Computing national curriculum in England and Wales (Department for Education, 2013) attempts to address all aspects of the arguments for computers in the curriculum, encompassing technology as the subject of study and as a tool for learning and wider application. The curriculum was introduced as a new subject from 5-16 with the intention of preparing learners to be competent users and programmers with the skill of 'computational thinking'. There are parallels here with the arguments over the STEM agenda in schools, where subjects have been introduced into a compulsory curriculum in order to increase general knowledge and promote uptake of further education and training and related careers.

The success of these curriculum initiatives is difficult to measure. There have been some encouraging increases in STEM subject uptake at post 16 including among girls, but there is still some way to go to reach either the total numbers required or a truly diverse population of scientists, engineers or mathematicians.

The evidence base for overall positive impact of the introduction of these subjects into the primary curriculum is slender. There is data suggesting that more experience of these subjects in wider society e.g. museums, publications, careers of adults in their lives and their 'STEM capital' (cf. Archer et al., 2017) influences attitudes. However, we do not know whether science or coding in the primary curriculum has a positive effect on understanding or uptake at 14, 16 or beyond. It is possible that these subjects being taught too soon, or by untrained teachers, has a negative effect. But we simply do not have firm evidence either way.

Identifying impact

The current evidence base for the effect of computer use on educational outcomes is generally of two types:

- Large scale studies where local variation may be lost as the outcomes tend to the mean and detail of specific interventions are lost.
- Small-scale studies which may not be generalisable and where the precise causes of variability in outcomes is not usually clear.

The most recent comprehensive published review of relevant meta-analyses is to be found in a report for the EEF in 2012 (Higgins et al., 2012). An update to this by Lewin and Smith is in preparation at the time of writing and was used to inform the 2019 EEF guidance report. Throughout, the measure used most frequently to indicate impact on learning in empirical studies is almost always an existing test performed on paper. The OECD uses tests of mathematics and reading as proxies for the effect of any variable on overall achievement and school effectiveness, not least as such data have widespread relevance in international studies. In the UK, large scale studies use Key Stage tests and GCSE results since these are the measures used to evaluate the efficacy of schooling and hold schools accountable (e.g. ImpaCT3). This does leave open the question of whether use of computers develops other skills not captured in these tests, and if the reading and writing of texts on screen is so different that it interferes with the parallel skills on paper. The 2013 OECD PISA tests attempted to address this by introducing a test of reading from a digital text which required both decoding of the written text and navigation of the information structure. The results were inconclusive with some of the best results achieved in countries where screen time is lowest (OECD, 2015a, 2015b).

Taken in the round, the evidence base so far does not support the argument that computer use in schools (or use of computers out of school) correlates with significantly improved results in current high stakes assessment. Nor is there evidence that access helps to bridge the divide between the disadvantaged and other learners. So, whatever the theoretical promise of connected digital technologies, it has yet to be realised in terms of systemic educational achievement as currently measured. Moreover, this finding has been remarkably consistent over some 50 years, even though the technology itself has developed and changed significantly and become more widely available in schools.

This then raises the question of whether the theoretical value of digital technologies to support current educational attainment can in fact be realised, and if so what conditions need to exist for this to occur? Can students who use an investigative, collaborative approach to subject based learning, using digital resources and tools, guided by a knowledgeable teacher well versed in the appropriate pedagogies, do as well or better than their peers who experience a didactic (tell and practice), paper-based curriculum? And even if both cohorts get good grades, are they equally prepared for what comes next? Indeed, given the possible consequences for these students, is such a cohort study even ethical?

The apparent disconnect between theory and practice when it comes to the use of digital technology in education raises four important questions which the current evidence base is inadequate to address:

- What typology of computer use has most relevance for teaching and learning? What are the key variables?
- Are the theory and rhetoric surrounding technology and learning simply wrong? Why is there is no clear link between use and outcomes?
- Is the practice flawed such that the potential is not being realised?
- Is the data gathering flawed such that any gains are being overlooked or lost through aggregation?

Nonetheless, there are four factors which emerge as central to an understanding of the current situation and the evidence base relating to technology use in the classroom; curriculum, pedagogy, teacher development and assessment. The next section looks at each of these in turn.

Curriculum

The differentiation in education between the computer as an object of study and a tool for learning has been evident from the earliest days of the microcomputer in the 1970s. More recently the notion of digital literacy has also emerged – the concept of the ability to 'read' and 'write' media in digital forms being elevated in importance, by advocates, to the level of reading and writing printed texts on a page (e.g. Royal Society, 2017). Currently in the UK nations, there is a mandatory requirement for aspects of all three of these elements of Computing in the statutory 5-16 curriculum, described as computer science, information technology and digital literacy respectively.

The national curriculum for computing aims to ensure that all pupils:

- Can understand and apply the fundamental principles and concepts of computer science, including abstraction, logic, algorithms and data representation.
- Can analyse problems in computational terms, and have repeated practical experience of writing computer programs in order to solve such problems.
- Can evaluate and apply information technology, including new or unfamiliar technologies, analytically to solve problems.
- Are responsible, competent, confident and creative users of information and communication technology.

(DfE 2013)

The biggest change for most schools was the introduction of the computer science element, particularly in the form of coding and to introduce this at the age of five. The challenges this posed in terms of teacher preparedness and access to resources are dealt with elsewhere in this paper. There are however a number of interesting questions relating to whether the introduction of coding has or will fulfil the intention to switch on more pupils, and particularly more girls, to the potential of coding as a vehicle to develop 'computational thinking' and/or the idea that a career in computer science is for them.

What should be studied?

It is perhaps hard to believe that under the 1944 Education Act, the decisions regarding the exact curriculum taught in a school were ultimately with the headteacher of any particular school. Those days are long gone and since the 1988 Education Act and the introduction of the National Curriculum, the definition of the curriculum for each of the nations of the UK has been a matter of government policy. Each time there has been a major overhaul, subject experts have been consulted as well as education researchers, headteachers and teachers. These exercises have for the most part been at the level of subject for the secondary and often the primary age ranges. This does leave some of the fundamental questions unexamined, including 'what is the purpose of education?' Given the unenthusiastic welcome this question received when broached by the Chair of the Education Select Committee in 2016, this is perhaps unsurprising. It seems many think the answer to this question is self-evident. Nonetheless there are implicit assumptions on purpose in the current definitions of the curriculum which have far reaching consequences for those being taught.

Presumably most would agree that the purposes of education include providing for the intellectual, psychological, physical and spiritual welfare of children and young people. There is then some debate as to the balance between learning for general development and preparation for the world of work and further, often heated, debate on what any of this should look like in detail. The balance between the general and the specific in STEM – including computing – tends to revolve around the sticky problem of what everyone needs to be an informed agent in a STEM rich world, and what preparation those who will specialise and take up careers in those fields will need to ready them for apprenticeships, further and higher education in their chosen specialism. Computer science is one of a list of school subjects which fall under the wider STEM definition, arguably at the expense of the use of computer technology in the Arts, Languages and Humanities. The debate around traditional science subjects is the most well developed and longest running. The changes in status of Separate, Single and Double award integrated/combined Science subjects over recent years is a manifestation of this.

Unfortunately, few of these debates are illuminated by strong evidence and many of them are rife with opinion and informed by ideology. For example, in the 1980s - amid much concern at the poor uptake of physical sciences by girls post-14 - there was a move to develop and promote integrated science curricula which would provide a mix of all three core sciences until age 16. The theory was that all students would then be equipped to make better informed choices for post-16 and have a wider range to choose from. There was also the added bonus that in taking only two, as opposed to three, subject slots in the timetable, there was more room for a broad and balanced curriculum to age 16.

However, the assumptions behind these changes were based on evidence that was at best scant and data on the long-term effects of these changes is patchy. It is possible to look at the trends in uptake and make inferences which suggest the changes did not have the impact hoped for – females remain under-represented in STEM generally, although there are some improvements in certain areas and these merit better research to understand them. The drive to return to offering three separate sciences did not wait for such evidence.

> '…less than 1 in 8 of the engineering workforce is female; boys are 3.5 times more likely to study A level Physics (in England, Wales and Northern Ireland) than girls; and five times more likely to gain an engineering and technology degree.'
>
> Engineering UK, The State of Engineering, 2017

One obvious gap in the data is longitudinal comparative studies of students following different curriculum routes. Any such study would also have to consider the external context of the cohorts as the influence of what Archer has coined 'science/STEM capital' is possibly more important than any school experience (Archer et al., 2017). Furthermore, in reality, the choice is often made at school level with few students being in a position to make an entirely free choice at 14.

Arguably, there are parallel issues in computing, with computer science seen as the more difficult and less 'girl-friendly' aspect and digital literacy and information technology seen as more accessible. The Education Reform Act of 1988 made ICT a compulsory subject for all pupils from 5 to 16 in maintained schools. The ICT curriculum focused on applications of technology and its use across the curriculum to support learning – although there was little evidence of the latter actually becoming established (Ofsted, 2011). The phasing out of ICT and its replacement with Computing in 2013 was seen as a move to make the subject more robust by adding computer science, particularly coding, to the ‘softer’ elements found in ICT (Royal Society, 2017). Early data suggests that an unintended consequence is that the number overall who take any aspect of computing at GSCE level is static at around one in five students but the gender balance in computing compared to ICT has moved sharply in the wrong direction from 39% to 20% female (ibid). Could it be that the drive to increase specialist knowledge for all has resulted in less general knowledge for all?

When should it be studied?

The question of when to introduce specialist subject experience into the curriculum remains a live one and never more so than in relation to computing. Timing of the introduction of computing as a whole, or its three constituent elements, is an interesting variable which could be studied through an international study since some countries do not have computers in the classroom in the early years. The point at which learners were first excited by computer science could also be investigated through the experience of those who have chosen to take further study or enter jobs where they use computer science. This could be compared with experiences of those who could have become computer scientists but chose not to, e.g. women with A levels in Mathematics and Physics.

Projects such as Code First Girls (https://www.codefirstgirls.org.uk/) give access to skills and knowledge in computing science to women who have successfully graduated in other subjects and then realised they need some computer science to progress their ambitions. The motivation provided by the need to develop a skill compared to de-contextualised experience in a school curriculum is an interesting one here. Wellcome data (2017) suggests that a significant number of girls shun computer science because they do not see it as relevant to their future. This number is far greater than those who see it as too difficult – so there is also a question here relating to timely careers information.

There is a common pattern in curriculum policy development. A recruitment drought in an area or a problem of lack of understanding or sympathy in the public at large, often results in a call for the explicit introduction of this subject into the school curriculum. Recent examples include science, modern languages, engineering, sex and relationship education and mental well-being. If this does not have the immediate effect required, there may then be a further call for the subject to percolate lower down the age range. The rationale can be summed up as ‘by the time they reach age X it’s already too late’ or ‘they’ve decided it’s not for them’. This is evident in the discourse in science education and latterly computing, where universal access to both subjects in primary schools is now mandatory in the UK as a result of curriculum reform. Similar curriculum change almost happened with modern foreign languages at primary and there are calls for the wider introduction of Engineering which is now available at GCSE.

The evidence base for these assumptions is, however, lacking. We do not know enough about the actual impact of the introduction of subject specialisms into the secondary or primary curriculum on later choices. In particular, we do not know the impact of the experience of being taught by teachers who are not qualified in the subject and who do not have the resources or development opportunities to become so. The evidence with regard to the importance of subject knowledge on effective teaching cited earlier should give some cause for concern (Coe et al., 2014).

Evidence from Mathematics in particular suggests simply making a subject compulsory is no guarantee of achievement. Standards in Mathematics have proved hard to raise and the shortage of suitably trained teachers is believed to be a critical factor.

> There are not enough specialist teachers of maths in primary, secondary and further education. There is an urgent need to:
>
> - Attract more high-quality Maths teachers into all sectors.
> - Train all teachers to teach Maths more effectively.
> - Support teachers through high-quality, career-long professional learning and provide career opportunities for maths teachers to develop their knowledge and skills.
> - Retain a greater proportion of the best teachers in classrooms.
>
> (ACME, 2014)

In Mathematics, all primary teachers will have studied the subject to some level and the more recent entrants to the profession must have at least a grade C/4 at GCSE. This is not the case in Computer Science nor is it likely to be realistic for the foreseeable future, although there is a requirement for a science subject at grade C/4 at GCSE. There is also the important distinction between knowing a subject and knowing how to teach a subject, which is addressed in the pedagogy section of this report.

In the case of coding, there are some interesting questions emerging about the relationship between the mathematics and computer science curricula. Recent work for the Royal Society (2017) suggests that schools are inclined to offer GSCE Computer Science to a smaller range of students than was the case for ICT, and that they favour those who are better at mathematics. The perception that you have to be good at maths to be good at coding is also evident in data from primary schools. Given the struggle to develop and promote effective maths teaching in primary and secondary schools, this could mean there is a potential multiplying effect here, making the successful learning of computer science for a wide range of learners doubly compromised. OECD data (2017) suggests this may be an issue with digital literacy and information technology as well.

Unless resource is focused on cracking the challenge of effective maths education for all, the imbalance in uptake of computer science among disadvantaged and female pupils will be hard to shift. The 2018 data on A level and GSCE uptake suggests that the percentage of girls taking and passing STEM subjects remains low despite a small increase.

Possible research questions which arise include:

- Under what conditions, and to what extent, do students exposed to computer science in primary schools develop a positive attitude towards the subject? Do any attitudinal effects persist and do they influence later choices? How are these data influenced by level of disadvantage or gender?

- To what extent do experiences in and attitudes to mathematics correlate with uptake, attitude and career choice? Again, are these data influenced by level of disadvantage or gender?
- How do students with different subject choices fare in further study? Do students with prior experience of computer science as a defined subject of study do better than or as well as than those with mathematics only, or Mathematics and Physics, when studying at the next level (transitions to include GCSE to A level or other relevant post-16 option) and post-16 to further study?
- Is there a case for better understanding of the role of technology in teaching specific, difficult and complex aspects of the curriculum as identified at a subject and age level?

Pedagogy

Research into learning with and about computers often suffers from a dissociation from the main bodies of literature on teaching and learning per se, and in relation to psychology and neuroscience. Baume and Scanlon (2018) make the case that there is an evidence base for seven principles for learning, which are necessary but not sufficient to create the conditions for effective learning regardless of what resources are in use. These include actions by learners and teachers and are, briefly: structure, high standards, learners being active in their learning and acknowledgement of their prior learning and approaches, spending lots of time on task, a collaborative element and effective feedback. In the same volume, Cukurova and Luckin (2018) look at the particular features of technology which support specific learning acts. However, in terms of matching affordances of technology with specific pedagogic elements, the picture remains incomplete and there is certainly no universally accepted rubric. There are also varying views of the right balance between technology as a subject of study and as a tool for learning.

Learning about computers

The recent literature reviews commissioned by the Royal Society look specifically at research and pedagogy in the area of computer science, in particular coding (Crick, 2017; Waite, 2017). This work is interesting, but like much education research it suffers from challenges of scale, repeatability and the complexity of the ecosystem it attempts to capture. Perhaps as a result of this latter point, the most interesting evidence comes from two development and research projects where universities worked with schools to develop, implement and evaluate coding in the curriculum. These projects tellingly involve developing specialist environments for coding and, by definition, have high levels of intervention at the implementation phase. Nonetheless they offer important models for the teaching of Computer Science in the classroom and are worthy of close examination and consideration in the design of any pilots in UK schools.[2]

Much of the research in this area looks at very detailed matters such as the effects of specific sequence of topics, the relative difficulty of concepts, the transferability of learning and the movement from simpler to more complex coding environments, e.g. moving from

[2] Grover, Pea, & Cooper (2015) created and tested a blended computer science course for middle school students, called 'Foundations of Advancing Computational Thinking' (FACT). See also Meerbaum-Salant et al. (2013).

block- to text-based languages. This literature does include some larger scale data sets, for example analysis of 150 programmes developed in the Scratch environment (Seiter & Foreman, 2013), perhaps the most widespread coding environment used in UK primary schools and developed specifically to provide a global platform for a community of young programmers by MIT. Scratch also has the attraction of being freely available.[3]

Clearly, there is an opportunity for a wider research programme looking at the way coding is taught. Care would be needed to mitigate the risk of collecting data on an imperfect or early implementation. Without this, any conclusions would be likely to fall foul of the same issue that plagues classroom-based research in all areas using technology; the theoretical potential is not realised in the classroom and we still do not know the extent to which this is due to the challenges of implementation.

The choice of specific content in the computing curriculum has been informed by experts in the field. There are research studies to inform how this content can be brought to life through teaching, although as with so much evidence the data sets are small and short term for the most part (Crick, 2017). There remain unanswered questions on the best ways to sequence, present and evaluate learning of this content (Waite, 2017). There also remains a wider question of the relationship of this content to the broader curriculum and how best to achieve the proposed learning outcomes, including preparedness for later study. The questions of when and how coding is brought into the curriculum have been raised as has the matter of which type of coding (see the section here on pedagogy).

It will be interesting to see over time whether these early experiences of programming languages, often specially developed for primary education, do in fact afford generalisable skill development that remains pertinent. At one time, university admissions advice to would-be computer science applicants was to study maths and physics at A-level as a better preparation for a higher education course. The concern was that deep understanding of the type of programming languages studied at GCSE or A-level was unlikely to help them with the languages they would meet later. Could it be the case that generalisable and transferable learning is absent or masked by the specifics of the environments studied in computing at school level?

There is an emphasis in the computing curriculum on the development of ‘computational thinking’ although a common definition of exactly what this is remains elusive. It would be helpful to have clarity on the relationship between computational thinking and other forms of rational calculative thinking, and whether there are analogues in other domains, particularly Mathematics. There are also implicit assumptions in the curriculum that experience of coding is needed to develop a generalisable and transferable understanding of what computers are and how humans have, do and will shape these technologies. This is a largely untested hypothesis and we do not know how far this understanding can be honed through other experiences including the use of unplugged resources.

[3] The results of a major Education Endowment Foundation review of the efficacy of this work to support learning are expected in 2019.

Learning with computers

There is a very large literature going back over 40 years on learning involving computers across the curriculum. Studies in STEM subjects tend to predominate but use of computer-based tools in the Arts, Humanities and Creative Subjects are just as important. Most current studies do not include coding as a vehicle for cross-curricular learning, but some do e.g. the Logo school. There are journals dedicated to the subject of computer assisted learning and for over 30 years in the UK there was a government agency (MESU, NCET and then Becta) which commissioned many pilots, evaluations and research including large cohort longitudinal studies across phases and the entire curriculum. Much of the resulting literature from these large-scale UK studies is now hard to access since the agency closed. However, at the risk of over simplification, the overall answer to the question of whether computer use in the classroom enhanced learning outcomes was – it depends, but generally not much. This is further substantiated by the work of Hattie (2009). From analysis of 161 studies involving technology, Hattie found an overall effect size of 0.34, though the range was 0.01 to 0.57. Magana (2017) concludes:

> *A reasonable inference can be made that the low impact of technology on instructional quality and student achievement is tied to at least two factors that are derived from the extant literature: 1) Digital tools are generally not used to directly enhance instruction and learning; and, 2) When digital tools are used, they are employed to simply supplement the tell and practice model of teaching and learning (Cuban, Kirkpatrick & Peck, 2001; McFarlane, 2015; NEA, 2008; Richtel, 2001).*

In all this data there are many studies where the only common factor is the involvement of a computer and, when disaggregated, there are some areas which are much more promising than others. For example, there is good evidence that well designed practice software enhances learning of computational processes in mathematics. But even here, the effects depend for the most part on how the technology is used as much as if it is used at all. The biggest factor is the teacher and how she or he frames the use of the resource. This is not news, see for example Underwood and Brown (1997).

An area which does have a large and coherent literature produced by a very active international community is that of computer-supported collaborative learning. The literature ties in with that of collaborative learning without computers and some of the most impressive work also involves the work of computer engineers who develop software specifically to scaffold learning – i.e. provide a framework within which learners are supported - as proposed by the underlying theoretical frameworks. There are also large cohort studies in international contexts to evidence the impact (Caballero et al. 2014; Szewkis, et al. 2011; Echeverria et al. 2011; Mitnik et al., 2009; Nussbaum et al. 2009). This is all relevant to the area of 'paired programming' which is of interest in the pedagogy of coding. We know from the literature on collaborative learning that it can be highly effective, that the relevant skills have to be acquired (effective collaboration is rarely spontaneous in younger learners) and that use of software designed to scaffold collaboration is effective in enhancing learning outcomes.

What is less clear is the overall effect of coding per se on learning in other domains. Papert (1980) expressed strong belief of this in relation to Logo. He believed that learning and using Logo would provide a framework in which other domains could be learned, particularly

Mathematics. But evidence to support this assertion is lacking. So too is evidence that children and young learners left to work with digital technologies without appropriate framing and guidance spontaneously make learning gains. Where this has been looked for, it has not been seen (Cristia et al., 2012).

It is likely that, although the literature is diverse and largely draws on small, short term interventions, the variability of results is due to the complexity and variability of the interventions being studied. As a result, two classrooms where the same computer and software is being used can produce very different results. The versatility of digital technologies means that there is a very strong chance the resources are being used differently in the two contexts. With digital technology to support wider learning it seems it is very much a case of not *what* you do so much as *how* you do it. This means that any study attempting to capture learning impacts needs to use very closely controlled experimental groups where a common rubric is used by all the cohort.

There are tantalizing glimpses of what could potentially be achieved when technologies are used to support learning matched to known models of effective teaching. Magana (2017) notes that:

> *'very large effect sizes were observed for teachers whose instructional behaviors matched those previously identified by Marzano (2007) as having a high probability of positively impacting instructional quality.*
>
> *'… large effect sizes might be likely when educational technologies are intentionally used to enhance the impact of highly reliable instructional strategies. Such an idea represents even greater cause for renewed optimism—and further investigation.*'

This opens up wider questions of the pedagogic models which are familiar to and practised by teachers in the UK. Unless these are robust and understood, then the chances of appropriate application and integration of technologies are likely to be reduced.

Research questions which could lead to insights include:

- Which, if any, pedagogic models dominate teaching in particular phases and subjects? Could applications of digital technology support each of these and how?
- How well are the underpinning models explicit to the teachers, and can they use this knowledge to rationalise their use or non-use of technologies?
- To what extent is the use of digital technologies embedded in dominant pedagogic models?
- Is there a case for better understanding of the role of technology in teaching specific, difficult and complex aspects of the curriculum, including Computing, as identified at a subject and age level?

Teacher development

In general

“The quality of an education system cannot exceed the quality of its teachers.” This statement from an international McKinsey (2007) report, made originally by a South Korean policy maker, has been widely repeated. Husbands (2013) takes issue with it however, since he asserts that the key variable here is the quality of the teaching, not necessarily the teachers. Moreover, he argues, the quality of teaching can be improved through effective teacher development whereas waiting for better teachers to enter the system would take a generation.

Historically, teacher development has been in two distinct phases, initial teacher training or education and continuing professional development. Recent developments are attempting to make professional development during the first five years of teaching more coherent, with clear recognition of progress and increasing knowledge and skills. A trial is currently being carried out by the Chartered College of Teaching and the Education Development Trust, funded by the DfE.[4]

Initial teacher training/education

It is some time since there was a national curriculum for initial teacher training/education. Yet in 2001 there was a comprehensive statement of the knowledge and skills relating to information and communications technology that should be covered, with a particular emphasis on use in subject teaching.[5]

This includes the following:

- Trainees must be taught how to decide when the use of ICT is beneficial to achieve teaching objectives in the subject and phase, and when the use of ICT would be less effective or inappropriate.
- Trainees should be taught what the implications of these functions are for achieving teaching objectives in the relevant subject(s).
- Trainees must be taught how to use ICT most effectively in relation to subject-related objectives.

The subsequent exemplification and detail in the 2001 report goes far beyond today’s curriculum for Computer Science.

Published evidence on the experience of today’s trainees in this area is thin. Clearly the emphasis and examples that teachers meet at the start of their career are likely to influence their understanding and competence with technology enhanced teaching and learning. This is an area which needs further research.

[4] See accelerate-teaching.co.uk

[5] See https://webarchive.nationalarchives.gov.uk/20010413154813/ http://www.dfee.gov.uk:80/circulars/4_98/annexb.htm

Continuing Professional Development

A recent review of teacher professional development (Weston et al. 2016) commissioned by the DfE, reported that in-service or continuing teacher development is extremely uneven and varied in form. The opportunity any given serving teacher has to access professional development is somewhat haphazard. The same expert group defined a standard for effective CPD as follows:

> *Effective teacher professional development is a partnership between:*
>
> - *headteachers and other members of the leadership team;*
> - *teachers; and*
> - *providers of professional development expertise, training or consultancy.*
>
> *In order for this partnership to be successful:*
>
> 1. *professional development should have a focus on improving and evaluating pupil outcomes;*
> 2. *professional development should be underpinned by robust evidence and expertise;*
> 3. *professional development should include collaboration and expert challenge;*
> 4. *professional development programmes should be sustained over time;*
>
> *And all this is underpinned by, and requires that:*
>
> 5. *professional development must be prioritised by school leadership.*
>
> Weston et al. 2016

In a digital world

All of this suggests that the school a teacher is working in, and the leadership of that school, are critical factors in determining if there is any professional development as well as how effective it might be. However, this does not appear to take account of the access teachers now have to professional communities operating online and outside the normal hierarchy of schooling. Perhaps the largest of these in the UK is operated by TES online where thousands of teachers can access over 700,000 resources largely posted and reviewed by other teachers. They can also join online community discussions on topics from early years to career progression which attract thousands - and hundreds of thousands, in some cases - of messages. This is remarkable in a world where many such community offerings struggle to attract attention.

The first online communities were formed by and for teachers of children and young people with special educational needs more than 20 years ago. For many years the government agency for information technology supported the SENCo (SEN co-ordinators) online forum. These teachers were often the only one in their school with this responsibility, supporting some of the most challenging students in terms of their learning needs. Access to others with similar requirements for professional development and more experience proved revolutionary. Since that time the sophistication of the methods of communication, and the ease of access, have improved immeasurably. There is little substantive data on the levels of use of these services across the teaching workforce, the impacts they have on practice or on the professional identity of teachers. There is work on-going which attempts to shine a light on the most effective use of online communications in teacher development but it is early days.

When considering the five conditions for success in the recent CPD standard, it is easy to see how use of online and social media could support conditions 2, 3 and 4. Access to information and resources to develop understanding and use of an evidence base, communication to support collaboration and to sustain learning over time are all cheaper, more flexible and available at the most appropriate point of need when available online.

Recent work by the Chartered College of Teaching is focussed on giving teachers better access to research evidence that has relevance to teaching and learning. This development is in its early days, it is however unique in that it is potentially available to all teachers if they join the College as it is an online community offer, and it addresses research that goes beyond the usual disciplines of education research. For example, the spring 2018 issue of the College journal, *Impact* looks at neuroscience.

Such evidence-based analysis applied to practice for teachers, has previously been restricted to occasional events or one-off reports, which, whilst valuable, reach a smaller audience and can be hard to access over time. This extension of the professional knowledge base of teachers is to be welcomed. With the move of much pre-service teacher education into schools, the curriculum has had little time to look beyond the models and methods needed to work in the classroom.

Truly effective professional development for teachers is, however, a complex business. The effectiveness of different methods is largely unproven with no large-scale comparative studies available. However, Alexander et al. (2017) examine the anatomy of a successful intervention to change teacher practice and reveal how systematic and sustained this must be – and that is before the introduction of disruptive digital technologies.

> *'Funded 2014-17 by the UK Education Endowment Foundation as a promising 'what works' initiative for reducing underachievement among disadvantaged students, the professional strand entails induction and training in this approach followed by a reiterative programme of planning, target-setting and review using mentoring and video/audio analysis and structured into 11 cycles over two school terms.'*

Alexander, ibid.

The video/audio analysis mentioned here references another area of potential revolution in teacher development. Lesson observation has been at the heart of teacher education and ongoing development for many decades. Peer observation has been promoted as a way to share best practice within and between schools. A study commissioned and funded by the EEF, involving over 14,000 learners, found that well-structured teacher observation provided a low-cost intervention for trained teachers but that there was no measurable impact on the outcomes for learners at GCSE compared to a control group. However, they do admit that this may be because practice in the control schools was already effective. Again, this shows how difficult it is to distil the effect of a single intervention in a multifaceted ecology.

Having a second or more adults in the room immediately changes the dynamic. It is also costly given that the other teacher might well have had to travel or be covered for a lesson they would otherwise have been teaching. The recollection of the lesson may also be different for the observer and the observed, making an honest and open discussion of any issues a potential source of conflict. Having a record of the lesson which can be shared after the event, whether that be as a video, audio or written transcript, provides a common experience that can be analysed and discussed together. Videoing lessons and using these records to aid reflection and development of practice is hardly new – Elizabeth Goldman was pioneering this technique in the 80s and 90s (OTA, 1994), and Initial Teacher Training Establishments were regularly videoing students in the 80s. What has changed is the ease and affordability of digital recording and sharing. On the back of this, powerful tools to analyse, document and share practice have been developed. At the time of writing there are two pilot studies currently underway, funded by EEF, looking at the impact and value for money of such methods for teacher development.

What Professional Development?

Given the known variability and complexity of the field of computing technology in education, it is perhaps unsurprising that there is some debate as to the type and level of CPD teachers need to be able to use digital technologies more effectively both as a subject of study and as a tool for learning. The Royal Society report (2017) records that primary teachers are challenged to go beyond the basics of the coding curriculum. It seems few primary teachers are well versed in computer science, and programming in particular, and secondary teachers also need further development particularly where they lack post A level qualifications in computer science. As a response to this need, the DfE in England and Wales announced plans in November 2018 for a national network of school-based hubs to support teacher development at primary and secondary levels and drive uptake of computer science. This is backed by an £84 million investment from government and supported by established STEM specialists, the British Computer Society, the Raspberry Pi Foundation, and has some support from Google.

There is some debate as to whether there is any need for training in *operating* digital technologies per se, but there is agreement for the need for training in effective pedagogy using technology outside the context of the study of computer science. Although as we have seen, this in itself is a many-faceted problem. It does not appear from the initial announcement that the new National Centre will have the use of technology across the curriculum as its focus. At the time of writing it is fair to say that the evidence of what teachers need to know and be able to do to use digital technologies in the classroom is scant and varies, depending on the assumed model of effective use itself. This raises the question of the purpose and ethos of teacher professional preparation and development more generally. To what extent is it tailored to achieve the aspiration of the Cambridge Primary Review to equip every teacher to be able to give a coherent rationalisation of what they are doing and how they know it works? (Alexander, 2010)

Research questions which could lead to insights include:

- To what extent does the level of prior qualification of the teacher correlate to higher achievement of learners? If data on teacher qualification (to include CPD) and pupil attainment were available, questions such as ‘are qualified maths teachers better prepared to teacher computer science?’, and ‘does degree classification matter?’, could also be addressed.

- How are digital tools such as those which support classroom observation, information sharing and community building for teachers, being used to support CPD? What efficiencies are being exploited, and what impact, if any, are these having on teacher practice?

Assessment

Digital technologies have significant potential in both summative and formative assessment. In summative assessment – the test at the end of the course – it is possible to automate significant forms of assessment task from the simple closed answer question to free-text short essay questions such as those found in US college entrance examinations and these efficiencies have been in use for some time (see McFarlane ed, 2003 for examples). These certainly reduce the administrative burden on teaching staff, speed up the time taken to produce results and open up the potential for a 'test when ready' model, rather than having one date on which all candidates take the test. However, these are all examples of what Magana (2017) refers to as level 1, Translational, use of technology. It introduces efficiencies but does not change teaching or learning significantly.

Where such assessment instruments are used in formative assessment – those used to inform teachers and learners of progress – they offer the option of a quick feedback tool so that teaching can be adjusted accordingly. This approach also opens up the range of tools to include instant class feedback formats like the 'clicker' tools where each learner has a response device. In reply to a question posed to the class, students can offer a reply. The replies are aggregated and shown in an anonymised form to the whole class. If required, the teacher can track each handheld device to collate user-specific feedback. In this way, a teacher can engage learners in a dialogue in real time which explores their understanding and addresses misconceptions before they are embedded. Such feedback is helpful in pacing lessons appropriately.

The EEF Toolkit suggests that effective feedback can accelerate learning by up to eight months over a year.[6] This seems remarkable – and raises more questions, not least, what was happening to make learning so slow before the intervention? There are current studies underway looking at different forms of feedback including a digital method in maths. Overall however the evidence-base to support the use of digital feedback tools in formative assessment is patchy and often gathered by the developers of the tools in question. As the EEF guidance (2019) points out, what is key here is teachers having the skills and knowledge to make good use of any assessment data gathered to inform subsequent teaching.

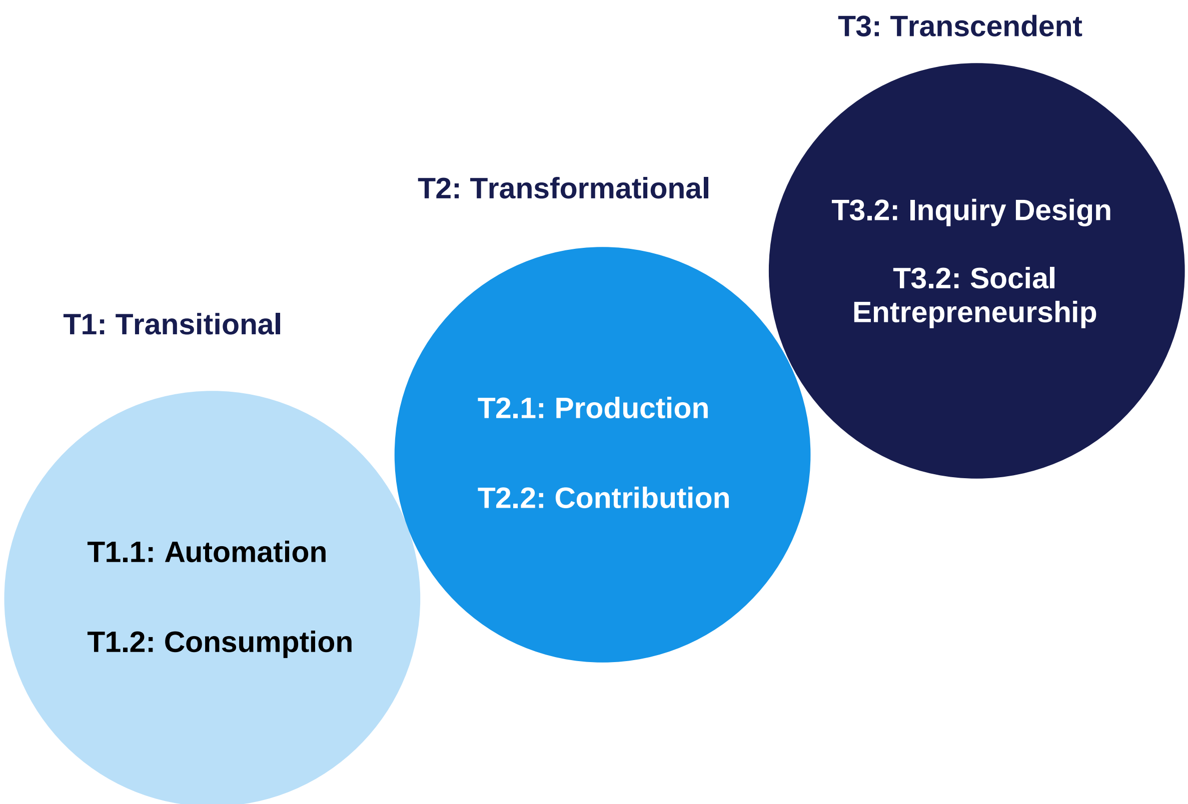
Perhaps the most significant tool to support ongoing feedback and reflection, is the use of a digital content management system. As with any digital tool used in schools, such a system must be easy to use and reliable (Fullan and Donnelly, 2013) for teachers and learners. It should then allow both types of user, teachers and students/pupils, to manage and store content. Teachers can make content available in class or out, see what learners have accessed and produced, comment and collate. Moreover, access to content can be managed such that other learners can also see selected pieces of work and comment. In the

[6] https://educationendowmentfoundation.org.uk/evidence-summaries/teaching-learning-toolkit

latest iteration of such tools it is also possible to use models of learner behaviours generated through the collection of very large datasets generated by many users. Systems using true artificial intelligence (AI) can then make assessments of learner behaviours and match this to the likelihood of a successful outcome, presenting content and support accordingly.

Digital content management tools support Magana's level 2, Transformational, use of technology where learning is transformed into a process of knowledge development and production. They also pave the way for his level 3, where teaching and learning are Transcendent, supporting inquiry design by learners and social entrepreneurship (Magana, 2017, p21).

T3 Framework for Innovation in Education



This model has been trialled in many schools and in many countries and well received by an impressive array of global thought leaders in education. The evidence for the efficacy of the T2 Transformational Technology Use strategies are directly synthesized from the Marzano (2007) study as ways to use technology to enhance highly reliable teaching and learning strategies such as 1) learning intention clarity, 2) student self-appraisal of their proximity to the learning intention, 3) student expression and representation of their conceptual understanding through demonstration, modelling and communication, 4) collaborative learning and 5) knowledge transfer. The T2 Transformational stage focuses on technology use to enhance student understanding of a defined body of content that is (or should be) aligned with high-stakes institutional or international assessments. The T3 Transcendent stage does not, as yet, have empirical evidence to demonstrate its efficacy. However, as the T3 Transcendent stage addresses inquiry and knowledge transfer in real-world contexts, an argument can be made that the positive impact of inquiry design and applied research are grounded on extant literature that dates back nearly 800 years since the early doctorates were awarded in medieval Paris in the 12th Century.

However, given current assessment frameworks it is entirely possible that the T3 pedagogy might lead to students gaining lower scores on standardised tests as they will have departed from the study of a defined body of content, on which the SATS are based. This is sometimes mistaken for a departure from the importance of content per se but knowing 'stuff' remains key and is the foundation for expertise. The challenge is that the learners should know about a given topic – but an enquiry led pedagogy means this may not entirely coincide with the specifics of the exam syllabus. Such students should in theory do well in assessment with open questions such as, 'Tell me what you know about X and why you believe it to be so', but less well on questions which ask, 'What date did emperor X rule Rome?'. This has been an argument made by proponents of a more skill-orientated approach to curriculum and its assessment but not one that has ever been the focus of a robust evaluation at scale. It is also an argument that has had little impact on national policy in the UK in recent iterations of the curriculum and an overhaul of high stakes examinations at 16+. Perhaps an example of this is the adoption of the 21st Century Science curriculum and its rather rapid replacement by the Coalition Government curriculum reforms.

The recently published DfE strategy for education providers and the technology industry (2019) offers an 'EdTech Framework for Change', steps 1 and 2 of which map onto Magana's T1 where technology is being used essentially to increase efficiency of administration and support existing practice. Step 3 refers to innovation but not transformation.

What research is needed?

The evidence base to date shows one thing very clearly – research which seeks to treat the use of digital technology as a single variable in teaching and learning is unlikely to cast any light on this complex landscape. The reality is that digital technologies are in themselves multifaceted and sophisticated, indeed this is where much of their power lies. Any given intervention which involves such technology will therefore be subject to interpretation at the point of use, leading to variation in operation and outcome. The evidence base suggests strongly that the mode of use is crucial when it comes to any acceleration of learning. To ignore this and simply to aggregate data from large scale studies or through meta-analyses loses variation and consistently produces at best a slightly positive impact. Until we can isolate and codify the variables which lead to successful application of different technologies, this is unlikely to change. First there is a need for a typography of technology as it applies to teaching and learning. Within each category there is then a requirement to define pedagogies which bring together the use of technology to support known models of effective learning. These could then be tested in the field, with particular reference to specific contexts.

In the foreword to the 2019 strategy, the Secretary of State for Education stated that; *'It can be difficult for education leaders to separate evidence-based practice and products from a vast range of gimmicks.'* The strategy also speaks of proven solutions. However, there is no suggestion as to how those solutions might be identified, nor is there a commitment to evidence gathering or research to do so.

In their report on progress of the implementation of the Computing curriculum, the Royal Society (2017) made a number of recommendations including one for the research community:

> *Education research funders, researchers, teachers and policymakers should develop a strategic plan that achieves:*
>
> - *the establishment of the long-term research agenda for computing education in schools;*
> - *a commitment to this programme by a number of stakeholders;*
> - *the development of UK capacity to conduct the research; and*
> - *the effective sharing of knowledge between researchers, teachers and teacher trainers*.

This highlights at least two variables likely to inhibit the scale and impact of any future research programme in this area, namely the capacity of the UK research community to carry out such research, and an absence of the means to disseminate any findings effectively. There is no doubt the work of the EEF has caused a major change in terms of linking practice and evidence, with a majority of headteachers using (or at least being aware of) their reviews and reports. As mentioned above, work by the Chartered College of Teaching has the mission and potential to address the issue of access and use of evidence for all classroom teachers. But it is unclear at this time whether there is a programme of capacity building likely to address the first challenge – that of an undersupply of suitable researchers. This is a factor which any intended research funding programme would need to address if it is to succeed.

The first point, the development of a long-term research agenda for computing education, needs amplification. The potential for and use of digital technologies in the classroom go beyond that laid out in the Computing curriculum. Indeed, studies at scale of highly specific interventions in clearly defined curriculum contexts may add significantly to understanding of where and when to use digital technologies to best effect. As an example of this kind of forensic approach at scale, there is currently a multinational OECD project looking at the teaching of quadratic equations in Mathematics as a proxy for effective Mathematics teaching more generally. The project is seeking to understand what teachers do differently in countries with a strong record in mathematics achievement compared to those lower down the international tables. It is not known at this time what use, if any, of digital technologies may be involved.

Any research which is to alter perceptions through a robust evidence base must be carried out at scale and over time. Small sample sizes and an absence of replication make most of the existing evidence unreliable, if interesting. Too many studies collect data in the early stages of an intervention and any outcomes cannot be assumed to have stabilised or to persist. As in Science, negative outcomes or those with no results are not published so we learn nothing of things which do not work or why.

There is a need to establish baselines in many cases – just what is going on in UK schools in terms of access, use and evaluation of the role of digital technology? How well prepared are teachers to teach about or use computing technology to support learning?

There is a lack of evidence relating to the impact of both earlier interventions and more recent ones. Just how has the introduction of Computing affected perceptions of the role of digital technologies in schools? Is use any more widespread now than previously, or are all available resources taken up with the curriculum time allocated to the dedicated subject? Has the primary computing curriculum inspired or deterred children from a love of programming and computer science? What did inspire today's undergraduates to study Computer Science, and perhaps more importantly, what put off the capable from this potentially lucrative career path?

When considering what an agenda for research might look like it is worth revisiting the recommendations from the Higgins et al. review in 2012. These recommendations reflect the best evidence we have to date of the factors affecting the impact of technology use on learning:

1. The rationale for the impact of digital technology on teaching and learning needs to be clear:

- *Will learners work more efficiently, more effectively, more intensively? Will the technology help them to learn for longer, in more depth, more productively? Or will the teacher be able to support learners more efficiently or more effectively?*

2. The role of technology in learning should be identified:

- *Will it help learners gain access to learning content, to teachers or to peers? Will the technology itself provide feedback or will it support more effective feedback from others, or better self-management by learners themselves?*

3. Technology should support collaboration and effective interaction for learning:

- *The use of computer and digital technologies is usually more productive when it supports collaboration and interaction, particularly collaborative use by learners or when teachers use it to support discussion, interaction and feedback.*

4. Teachers and/or learners should be supported in developing their use of digital technology to ensure it improves learning.

- *Training for teachers (and for learners), when it is offered, usually focuses on technology skills in using the equipment. This is not usually sufficient* *to support teachers and pupils in getting the best from technology in terms of their learning. Ongoing professional development and support to evaluate the impact on learning is likely to be required.*

5. Identify what learners and teachers will stop doing:

- *The use of digital technology is usually more successful as a supplement rather than as a replacement for usual teaching. Technology is not introduced into a vacuum. It is therefore important to identify carefully what it will replace or how the technology activities will be additional to what learners would normally experience.*

If further research is to advance our understanding of the relationships between technology use and learning, it is vitally important that there is some consistency in the design of the interventions under study. Moreover, it seems perverse to ignore the factors we know to be significant as outlined above. To summarise there should be in place:

- A clear rationale.
- An articulated role.
- Training and support in effective use.
- Alignment with existing timetable and resources.

Furthermore, the most productive contexts so far are those which include:

- Collaboration and interaction.

An evaluation programme which looks at established practice might unearth new insights providing that practice meets these recommendations – where it does not, we know that the chances of success are reduced. A research programme using interventions which adhere to the recommendations is an alternative or possibly complementary option. This would require a longer lead time since the interventions may have to be developed and need time to bed in to ensure that the findings are robust.

More forensic questions

Once it is established that we have teaching and learning contexts that satisfy the recommendations above, there are a number of research questions that can be explored with some expectation of generalisable and robust outcomes. Looking at the four areas considered in this report, there are a number of specific research questions and a potential programme of smaller research projects that emerge from the current evidence base. These appear in each separate section and are collated here for ease of reference:

Curriculum

- Do students exposed to the Computing curriculum in primary schools develop a positive attitude towards the subject?
- Do any attitudinal effects persist and do they influence later choices?
- How are these data influenced by level of disadvantage or gender?

- To what extent do experiences in and attitudes to Mathematics correlate with the above?
- How do students with different subject choices fare in further study?
- Do students with prior experience of Computer Science as a defined subject of study do better than or as well as those with Mathematics only, or Mathematics and Physics, when studying at the next level (transitions to include GCSE to A level (or other relevant post 16 option) and post 16 to further study?
- The use of technology in the classroom is more prevalent, and there is more evidence of effect, in maths and science. To what extent is this related to the epistemology of these subjects, or some other factor?

Potential research and development project:

To what extent do the Mathematics and Computing curricula support or interfere with one another? Is there scope for development of a curriculum and pedagogy for computer science and mathematics which is complementary?

Pedagogy

- Which, if any, pedagogic models dominate teaching in particular phases and subjects? Could applications of digital technology support each of these and how?
- How well are the underpinning models explicit to the teachers, and can they use this knowledge to rationalise their use or non-use of technologies?
- To what extent is the use of digital technologies embedded in dominant pedagogic models?
- Is there a case for better understanding of the role of technology in teaching specific, difficult and complex aspects of the curriculum, including **Computing**, as identified at a subject and age level?

Teacher development

- To what extent does the level of prior qualification of the teacher correlate to higher achievement of learners? If matched data on teacher preparation (to include CPD) and pupil attainment were available, it would be possible to explore any possible correlation between these two variables and whether higher qualifications in mathematics better prepare teachers to computer science.

- How are digital tools such those which support classroom observation, information sharing and community building for teachers, being used to support CPD? What efficiencies are being exploited, and what impact are these having on teacher practice?

Assessment

- There is much work on the development of different methods of computer supported assessment. However, the questions which remain are related to what should be assessed and how can this be accredited to best drive the implementation of a curriculum which addresses the current inadequacies as set out in the House of Lords report? Namely that learners complete their schooling ‘digitally illiterate’.

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