How England implemented its computer science education program

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Summary

Computer science (CS) education helps students acquire skills such as computational thinking, problem-solving, and collaboration. It has been linked with higher rates of college enrollment (Brown & Brown, 2020; Salehi et al., 2020), and a recent randomized control trial showed that lessons in computational thinking improved student response inhibition, planning, and coding skills (Arfé et al., 2020). Since these skills take preeminence in the rapidly changing 21st century, CS education promises to significantly enhance student preparedness for the future of work and active citizenship.

CS education can also reduce skills inequality if education systems make a concerted effort to ensure that all students have equitable access to curricula that provides them with the needed breadth of skills, regardless of their gender, ethnicity, or socioeconomic status.

Based on prior analyses and expert consultations, we selected 11-CS education country, state, and provincial case studies that may have lessons that can broadly apply to other education systems. These cases come from diverse global regions and circumstances and have implemented CS education programs for various periods and to different levels of success. As such, we have examined information to extract lessons that can lead to successful implementation.

This study will examine how England developed its CS education program of study. CS concepts have been part of the official English curriculum for over a decade, but reforms have encouraged wider participation in the last six years. Given that this is a relatively long period of implementation compared to many other countries' CS activities, this England case study can give us an understanding of how CS education activities can be improved over time.

An overview of CS education in England

For the purposes of improving teacher knowledge and expanding the scope of the curriculum, a nonprofit organization called Computing at School established a coalition of industry representatives, teachers, and parents in 2008. The organization would go on to play a pivotal role in rebranding the information and communications technology (ICT) program of study in 2014 to the computing program that placed a greater emphasis on CS (Royal Society, 2017). By changing the program, the government instructed schools to provide more rigorous instruction in CS concepts like Boolean logic and programming languages.

Executing the new computing program was a great challenge. Many teachers immediately felt uncomfortable with the new material (Brown et al., 2014; Sentance et al., 2013), regarding it as an exceptionally difficult subject to teach and learn (Royal Society, 2017). Before the new computing program, teachers were only offered training in ICT. From 2014-2018, the Department for Education (DfE) allocated modest funding for this purpose, and then fell short of its targets for training CS teachers, leaving schools with an insufficient number of qualified teachers (Staufenberg, 2018).

To improve teacher preparedness, Parliament and the DfE made significant investments in training CS teachers. In November 2018, they allocated 84 million pounds to establish the National Centre for Computing Education (NCCE) to train teachers (Cellan-Jones, 2019). Drawing on help from nonprofit organization partners, the Centre creates lesson plans and resources, runs training programs, and offers certification for preservice and in-service teachers. Since the Centre's opening, it has engaged 29,500 teachers in training, 7,600 of which have benefited from continuous professional development.

Lessons learned

England's experience developing its CS education program of study highlights four important lessons:

- The technology industry is an obvious resource for subject matter and pedagogy expertise that can help design an effective CS program of study. Yet, the government must also understand and incorporate teachers, who act as gatekeepers to the lessons taught in the classroom.

- Teacher training should be an immediate priority that requires ambitious funding and long-term planning. England took a modest approach to teacher training for the first four years, discovered that its strategy fell short of its original ambitions, and later opened a large center for training with much greater funding.

- Unequal access to quality CS education can persist despite a mandate that all students participate. Unequal opportunities to develop an interest in CS persist along racial, gender, and geographic lines, though it is possible that this will diminish over a longer time period.

- Issues around *what* and *how* CS education should be taught to make it accessible to all students still exist. CS was a self-selected subject until 2014 but making it mandatory means that more research on how to teach it effectively must be carried out.

In this case study, the term ICT refers to the program of study that had been implemented before 2014. "Computing" is a program of study that the DfE started to implement in the 2014–15 school year that incorporates topics like digital literacy, digital ethics, and security, but emphasizes CS as its principal component.

Origins and motivation of CS education

Post-war England made a significant early impression on computing technology innovations. Perhaps most notably, English innovators like Alan Turing, Ada Loveland, and Charles Babbage are credited for creating the Colossus, the first electronic digital programmable computer. However, England's reputation in CS started to decline in the late 1960s, when the British computing industry failed to compete with American-made IBM computers that flooded global markets. By the 1990s, even the U.K. government stopped buying British computers and home-grown computing companies had all but disappeared (Larke, 2019).

The demise of the domestic computing industry corresponded with the declining quality of England's computing education. The DfE deemphasized CS topics like programming and computational thinking for pre-16 age groups after the 1980s (Sentance, 2018). From the 1980s until the mid-2010s, neither the public nor the DfE were aware of the differences between CS and computer literacy (Brown et al, 2014). In theory, the intended ICT curriculum called for students to learn components of digital literacy, as well as CS and computational thinking (Royal Society, 2012). In practice, however, ICT teachers focused on the use of devices rather than teaching about hardware and software design. Hughes (2017), for instance, reports that students learned little more than how to use Microsoft Office. While digital literacy skills are useful for most contemporary jobs, England's ICT program during this period added little value to students' education. The Royal Society (2012) concludes that students would likely have learned digital literacy skills by themselves without school instruction. The Society offers four specific reasons for the ICT program's lack of rigor (Royal Society, 2012): (1) The curriculum opened itself to broad interpretation that allowed non-specialist teachers to reduce the subject to its easiest possible level; (2) Few teachers understood the subject matter well enough to teach beyond basic digital literacy; (3) There was a lack of professional development (PD) for these teachers; and (4) School infrastructure was ill-equipped for computing.

Advocates for reemphasizing CS in English schools made inroads starting in 2011. Eric Schmidt, former chairman of Google, gave a speech in Edinburgh in which he expressed his dismay over U.K. schools focusing on computer literacy instead of CS. Within weeks, Prime Minister David Cameron publicly agreed with Schmidt's assessment: "We're not doing enough to teach the next generation of programmers. One of the things you hear from the businesses here in Tech City is 'I don't just want people who are literate in technology, I want people who want to create programs,' and I think that's a real wake up call for us in terms of our education system" (Jones et al., 2013). Likewise, Nesta's high-profile Next Gen report explicitly argued for the DfE to add CS as a core part of the school curriculum, emphasizing that the industry needed to enhance its talent pipeline to improve growth over the coming decades (Livingstone & Hope, 2010).

The industry's push for CS coincided with two other major developments. First, the Royal Society released a report in January 2012 titled "*Shut down or restart? The way forward for computing in UK schools*," that described the poor state of ICT education and the need to introduce more rigor. Around the same time as the Royal Society report's release, the national curriculum in England had been serendipitously scheduled for review. Brown et al. (2014) conclude that the timing of these two events forced DfE to seriously reconsider the ICT program. The second development was that the government decided to include CS GCSEs (a set of standardized subject-specific exams that are either offered or required for 15-year-old students)[1] in the science category of the EBacc (English Baccalaureate), a program that measures student and school performance based on test scores in certain subjects. This change was significant because it incentivized schools and teachers to provide better quality education in that subject (Brown et al., 2014).[2]

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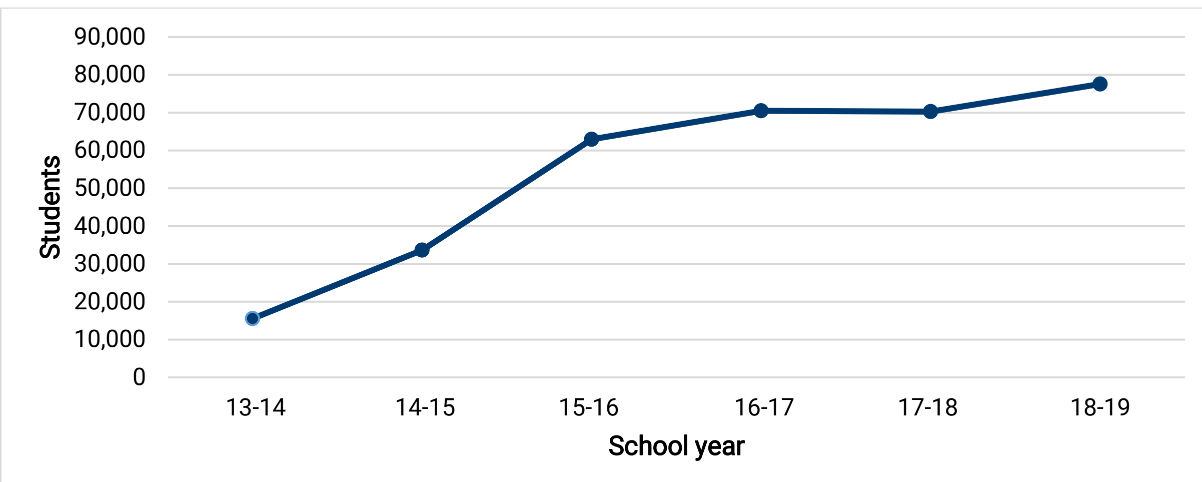
1 GCSE qualifications taken by students vary greatly, but schools are generally encouraged to offer a pathway that leads to students passing the exam.
2 EBacc status affected education quality for other subjects. A year after DfE announced that it would do this for foreign languages, for example, the portion of students that studied for that subject's GCSE increased from 36 percent to 51 percent in a single year (Tinsley & Han, 2012).

In 2012, Secretary of State for Education Michael Gove gave a major policy speech emphasizing the need for students to understand CS principles that endure despite rapid technological improvements. He proclaimed that CS should be taught as a serious academic discipline and announced that the DfE would encourage rigorous CS courses to be taught in public schools (Brown et al., 2014). After a review of the old ICT curriculum, the program of study was rebranded as "computing" and a greater emphasis on computer science was introduced.

A pilot GCSE was offered in computing from 2010, before the curriculum change. This then evolved into a GCSE in computer science by the 2013–14 school year. A-levels (the standard exam offered to students aged 17–18 for assessing applicants for university admission in the U.K.) always had a qualification in "computing," including CS principles like programming, but this qualification has been iteratively revised and rebranded as CS over the last five years. The number of students taking the CS GCSE has increased since the change in 2014 (Figure 1).

Figure 1. Number of students taking GCSE for computer science each school year, 2013–19



Source: Department for Education

By reemphasizing the importance of CS within English education, policymakers wanted to prepare England to enjoy the economic boom that technology would provide in the coming decades. Industry supporters and government officials wanted to give English youth the ability to find lucrative technology jobs, or to become entrepreneurs themselves. The Royal Society’s (2012) “Shutdown or Restart” report further argued for an emphasis on CS, saying that it will improve students’ thinking skills and enhance their creativity.

Box 1. A timeline for the development of computer science education in England

Mid-1990s – ICT class initiated in England

2008 – Computing At School founded to promote CS

2012 – The Royal Society’s “*Shutdown or Restart*” report triggers State Secretary Gove to announce reform to ICT curriculum

2013 – DfE grants British Computer Society (BCS) 2 million pounds to train master computing teachers

2014 – CS-intensive curriculum implemented in rebranded “computing” program of study

2014 – CS General Certificate of Secondary Education (GCSEs) and A-level exams become available

2016 – BCS misses teacher training targets

2017 – Royal Society’s “*After the reboot: computing education in UK schools*” report reveals need for better teaching quality, more ambitious funding, and rigorous research

2018 – Parliament approves funding for the National Centre for Computing Education

Institutional arrangements for executing CS education

The DfE is the ultimate authority on CS education, and all other subjects, in England. Nevertheless, the DfE has relied on outside organizations for help in executing its CS education responsibilities. The NCCE, for instance, is run by a consortium made up of BCS, STEM Learning, and the Raspberry Pi Foundation, three nonprofit organizations dedicated to advancing the computing industry and CS education in the country.

Headed by the Secretary for Education, a cabinet-level position, the DfE oversees all matters related to hiring and firing, teacher recruitment, and curriculum development. The Secretary has been highly involved in the development of CS education, which represents one of the most innovative and substantial changes to the curriculum over the last decade. Multiple sources cite Secretary Gove's now famous 2012 speech, in which he emphasized the need for students to understand CS principles as a catalyst for CS education's 2014 revival (Brown et al., 2014; Jones et al., 2013; Larke, 2019).

The BCS's role in the NCCE is to run CAS Communities (formerly known as hubs, small local groups of teachers), and lead on certification of teachers. The Raspberry Pi Foundation and STEM Learning have stepped in to share other responsibilities. The Raspberry Pi Foundation creates lesson plans, resources, online courses, and work schemes, both drawing on existing materials and innovating new ones. Raspberry Pi also researches best teaching practices and disseminates information. The third nonprofit consortium partner, STEM Learning, commissioned 40 regional hubs and runs face-to-face training programs. The hubs are designed as centers for teachers to find regional support (Sentance, 2018). All these training opportunities offer certification for either in-service or preservice teachers. Since NCCE's opening, it has engaged 29,500 teachers in training, 7,600 of which have benefited from continuous professional development. Additionally, the NCCE is developing an evidence base that shows age-appropriate teaching methods.

Civil society’s role in supporting CS education

Civil society plays an important role in establishing and improving CS courses in English schools. This is particularly true for the BCS, whose Academy of Computing runs four initiatives to advance CS education: Computing At School (CAS), Barefoot Computing, teacher training scholarships, and teacher certification.

CAS started as a grassroots initiative to develop a national vision for CS education. Comprised of teachers, parents, representatives from the DfE, and big tech companies, it was founded in 2008 with the goal of establishing CS as the “fourth science” in English schools alongside biology, chemistry, and physics. Soon after its founding, CAS formed a partnership with the BCS and would become BCS’s most visible and impactful initiative (Jones et al., 2013).

CAS started lobbying the government to place greater emphasis on CS education and for DfE to include CS in the GCSEs (Jones et al., 2013). The program also started organizing and training CS teachers through annual conferences (Brown et al., 2013; Crick & Sentence, 2011). Using English universities as regional centers, CAS ran the Network of Excellence, which promoted and supports teacher PD and engagement activities until 2018.

The Barefoot Computing initiative provides resources on computational thinking across different subject lessons in a way that is accessible to teachers that have no prior expertise. These lessons are cross-curricular and involve both digital and analogue activities to engage student interest. Barefoot resources are freely accessible to teachers and include lesson plans, tutor notes, and workshops for other primary teachers to meet and compare notes. DfE launched Barefoot Computing in 2014 before handing it over to BCS and BT, a British telecommunications company (Royal Society, 2017). The Royal Society’s (2017) survey of 341 primary school teachers and 604 secondary school teachers in the U.K. found that 17 percent of primary school teachers indicated that Barefoot was a helpful resource for CS education, the highest rating for supporting organizations amongst primary school teachers. However, CAS was by far the highest rated amongst secondary school teachers at 37 percent and the second highest amongst primary school teachers at 15 percent.

Additionally, the BCS has helped train preservice teachers and certify in-service teachers by granting scholarships for university students to gain IT skills that will prepare them to teach in secondary schools and access PD resources and continuing PD after graduation.

To keep up with demand for CS education, the DfE has to rely on teachers who have previously specialized in other subjects. To address this issue, BCS delivers two types of certifications. Both are free to teachers and are provided entirely online. One trains, assesses, and certifies teachers in *subject knowledge,* such as coding in Python, algorithms, and data structures. The other program certifies teachers in *pedagogical approaches*. To gain this certification, teachers must complete three parts of the program: reflections on PD, a programming project, and a classroom pedagogy investigation. This includes at least 20 hours of PD that can include workshops, CAS hub meetings, and/or evidence of using an open online course.

Computing program course development and standards

The rebranded "computing" curriculum in 2013 prioritized CS concepts, as opposed to computer literacy topics that the "ICT" teachers typically emphasized before the change. Many teachers, however, perceived that their concerns came secondary and have not implemented the new program of study as the DfE intended.

In 2012, the DfE was writing a new curriculum for all academic subjects but took a unique approach to the ICT curriculum. DfE invited the BCS and Royal Academy of Engineering to coordinate a broad group of stakeholders charged with writing a new study program for computing (Jones et al., 2013). DfE invited two successive working parties and community consultations. The first consultation group consisted of representatives from BCS, the Royal Academy of Engineering, Vital (the Open University's ICT teacher professional development program), ITTE (the Association for Information Technology in Teacher Education), and Next Gen (a lobbying campaign to meet the skills needs of the U.K.'s video game and visual effects industries), as well as two academics from university CS departments, three CS school teachers, and representatives from university teacher education programs (Larke, 2019). In September 2012, this group sent a full draft of its curriculum that focused on implications, applications, and foundations of ICT (Twining, 2012, September 20). A month later, a closed consultation redefined these three areas as CS, information technology, and digital literacy (Twining, 2012, October 1) and strengthened the CS component. In conversations with members of the original consultation groups, Larke (2019) understood that teachers felt that their interests had been betrayed in favor of the technology industry in the end. According to Larke (2019), "Members of industry, rather than the mixed-profession working groups they had led, had been invited to write the final draft of the curriculum, resulting in digital literacy and the 'dirty word' of ICT being removed entirely in favor of a computer science focus." As such, DfE rebranded the program of study from ICT program to "computing," emphasizing a shift for more technical rigor.

The final draft was published in February 2013 for public consultation and revision (Jones et al., 2013). In September of that year, the DfE published the resulting national curriculum for computing, which aims to ensure that all students:

- can understand and apply the fundamental principles and concepts of CS, including abstraction, logic, algorithms, and data representation;
- can analyze 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; and
- are responsible, competent, confident, and creative users of information and communication technology.

The detailed standards seek to achieve all these goals as lessons get more complex with each grade advancement. For example, students should "understand…that programs execute by following precise and unambiguous instructions" by age seven. By age 11, they should "use sequence, selection, and repetition in programs." By age 14, they should be able to "use two or more programming languages" (Department for Education, 2013).

Given the differences between expected and actual (reported) classroom hours spent on computing, this intended curriculum appears to not be carried out in practice. The Royal Society (2019) reports that about 152,500 hours of ICT were taught to students of ages 11–18 in 2013. By 2018, only 102,338 hours of computing were taught for that age group, a 33 percent decrease in five years. Further, extensive classroom observation and teacher and student interviews in four public primary school classrooms reveal that computing had been taught much less than is mandated by the DfE. According to Larke (2019), teachers often minimized or outright rejected the mandated curriculum that they felt conflicted with their professional knowledge.

Teacher recruitment, preparedness, and professional development

England initially provided modest funding teacher PD through the Network of Excellence, a BCS program. As time went on, however, it became clear that this approach was not ambitious enough to achieve its goals. Parliament would later open a large center for training with much more funding.

Teachers showed signs of low confidence in their knowledge of CS subject matter and pedagogy since the beginning of the ICT curriculum (Brown et al., 2014). In a web-based questionnaire of 86 teachers taken right before the computing program of study was first implemented, 71 percent of respondents felt that they needed "guidance on ways of teaching computing" (Sentance et al. 2013). More recently, the Royal Society reported in 2017 that almost half of teachers in primary and secondary schools ranked themselves as having low confidence in their theoretical and technical computing knowledge. DfE had to make a plan to prepare its teachers.

DfE granted BCS 2 million pounds in 2013 to create the Network of Excellence, charging it with creating learning hubs and training a pool of "master" CS teachers. To become masters, teachers volunteered to undergo 120 hours of guided learning in the first year of the program. In the second year, they also received mentoring and coaching help (Royal Society, 2017). At the time of the grant, the Network of Excellence set a goal of training 400 master teachers by 2015. State Secretary Gove's strategy for funding this program was for the trained teachers to "spread good practice through the system and help schools to teach (the) new computing curriculum," the idea being that all CS teachers would be able to draw support from a master teacher (Dickens, 2016). According to the Royal Society (2017), however, the number of master teachers at the time could not be expected to provide this kind of support to all the 25,000 primary and secondary school teachers charged with teaching computing in England. The Society argues that the network would have to become much more substantial, training more master teachers and establishing more training hubs throughout the country. Indeed, by January 2016, the Network of Excellence had only trained 300 master teachers, drawing criticism from the political opposition for not meeting its goal (Dickens, 2016). It should be noted, however, that the Network of Excellence functioned on a budget of about 1 million pounds per year, a figure that pales in comparison to the 21 million pounds per year budget that would eventually be awarded to the NCCE in 2018. The Network of Excellence ended in March 2018 having trained 540 master teachers.

During this time, BCS also created 10 regional university-based hubs to lead training activities including lectures and meetings to facilitate collaboration as part of the network of excellence (Dickens, 2016; Heintz et al., 2016; Royal Society, 2017). These hubs made it easier for teachers in diverse regions of the country to participate in training activities and are still increasing in number.

Under the computing program of study, generalist primary school teachers need to learn elements of CS subject matter and pedagogy while secondary school computing education requires more specialized teachers. Thus, secondary school programming relies on teacher recruitment as well as training programs. Unfortunately, recruitment has also been consistently behind schedule as recruitment targets steadily increased since the start of the program. In the 2014-15 school year, DfE targeted 105 and achieved 90 new entrants (85 percent of the goal). In the 2018-19 school year, DfE targeted 265 and achieved 193 new entrants (73 percent of the goal). Thus, the number of new recruits has consistently increased from year to year, but always less than DfE had hoped (Royal Society, 2019). Granted, teacher recruitment typically falls short for all STEM subjects, but recruitment of computing teachers has fulfilled the smallest share of its goal. In 2017, for example, DfE had filled just 66 percent of the required entrants (Allen-Kinross, 2017; Sibieta, 2018). An underlying reason for the recruitment shortfall is that the difference in salaries between teaching and other professions are very high for graduates with CS degrees (Royal Society, 2019).

The government tried investing substantially in scholarships and bursaries for computing/ICT subject and teaching courses. Yet, there is no evidence of their effectiveness. Between the 2009-10 and 2015-16 school years, ICT/computing scholarships granted a higher amount than for other subjects but appeared to have the weakest effects compared to other subjects (Royal Society, 2019; Department for Education, 2018). When trainees move from the scholarship to a taxable salary upon securing a teaching role, their real net income often falls since the scholarship is non-taxable. As such, many scholarship recipients completed their training and then took jobs in the technology industry (Royal Society, 2017).

All of this resulted in the number of computing teachers in England declining from 15,400 in 2013 to 12,788 in 2018, a 17 percent decrease. Funding for the network of excellence master teacher program and the regional centers ran out in July of 2018. It was clear that the DfE needed a new strategy with more ambitious funding to substantially improve computing education quality.

These trends changed dramatically in 2018, when the government put much greater resources into recruiting and training teachers. The DfE announced an 84 million pound investment through 2022 to train up to 8,000 CS teachers (Cellan-Jones, 2019). According to Simon Peyton Jones, Chair of the NCCE, "(the Centre's) main goal is to support and equip, and provide resources for schools and teachers to turn that short dry national curriculum into a rich vibrant reality for every classroom in the land from age 6 through to 18 (Computing At School)."

In 2019, the NCCE announced that it would open 23 new computing hubs throughout England. These hubs offer support to primary and secondary computing teachers in their designated area, including teaching, resources, and PD (Snowdon, 2019).

The changes were needed. The Royal Society's (2017) comprehensive assessment of the new computing curriculum emphasizes that incorporating CS topics has been a challenge. According to the Society, most teachers consider CS a specialist subject rather than a mainstream one. It also provides survey results suggesting that teachers and students regard CS GCSEs as more difficult than other subjects. Most respondents thought that only advanced students should take CS GCSEs, potentially limiting the number of students who would try to pass the exam.

In just over two years, the NCCE has come a long way toward fulfilling its goals. Teacher training has accelerated since its opening. Per the NCCE's November 2020 progress report, some 29,500 teachers have engaged in training, 7,600 of which have benefited from continuous PD. Of those, 1,300 achieved CS certification as part of the Computer Science Accelerator, a new teacher certification program. Survey evidence indicate that these training programs improve classroom learning: 93 percent of teacher participants said that the NCCE "significantly benefited them," with the majority indicating that it helped them engage their student's interest. Most teachers also said that they were able to share training benefits with their colleagues. Further, there are now 35 computing hubs and 275 CAS communities of practice in England that provide peer support and networking opportunities for computing teachers.

CS inclusiveness

England has had some success reaching girls, as well as minority and rural students, with its CS education program but still has considerable work to do. For several years before 2014, between 35-40 percent of students taking the ICT GCSE had been girls (Cellan-Jones, 2019). The share of girls taking computing GCSE, by contrast, started at a much lower 15 percent in 2013, but has increased to an improved but modest 21 percent by 2020. For A-level exams, it increased from 8 percent to 15 percent over the same period (students choose three A-Levels and choose 9 GCSEs) (Cellan-Jones, 2020; Kemp et al. & 2019). The Royal Society (2017) provides explanations for this disparity. It reports that 55 percent of girls who did not take the CS GCSE in 2016 made that decision because they were "not interested in the subject," compared to just 38 percent for boys. Amongst the surveyed students, girls were also more likely than boys to say that they did not need CS "for future plans." Gender differences are common across STEM subjects across England, but they are especially pronounced for CS (Royal Society, 2017).[3]

To address the gender gap, various foundations, including the Raspberry Pi Foundation, STEM Learning, the BCS, The Chartered Institute for IT, and the Behavioural Insights Team created the Gender Balance in Computing project with 2 million pounds in funding from the NCCE. The initiative aims to increase the number of girls that choose to study a computing subject at GCSE and A-level by researching and piloting a series of new interventions. These include pedagogical approaches to teaching computing and relating informal learning opportunities that are often popular with girls. Trials started in 2019 and will run until 2022 in key stages 1-4 (ages 5-16) involving more than 550 schools (Sentence, 2019). This initiative works in conjunction with the NCCE to coordinate with participating schools and share research.

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[3] Girls from lower-income areas are more likely to take the GCSE than girls from wealthier areas. Also, white girls are less likely to take the exam than girls of color (Kemp et al., 2019).

The disparity in interest in CS also varies by ethnicity, though not as dramatically as gender. According to an analysis of administrative data, 5.5 percent of white students that attended schools that offer the exam took the CS GCSE in 2015 (Kantar Public, 2017). This is significantly more than the 4.1 percent of Black students taking the exam. Asian students were the most likely to take the exam of any ethnic group, with 7.5 percent taking it when available (including 12.7 percent of Chinese students). Opportunities to develop interest in the subject may cause differences in uptake by ethnicity. In the 2014–15 school year, white and Asian students were more likely to attend schools that offered the GCSE than Black students. It is plausible that schools that have more white and Asian students emphasize CS more than schools that have more Black students.

There is also reason to doubt the quality of computing education in rural schools compared to schools in urban environments. According to a survey done by the Royal Society (2017), teachers that are based far away from city hubs often feel isolated, making it difficult for them to participate in networking meetings or PD activities. Online courses can circumvent this problem to some degree and are becoming more popular. Yet, rural teachers require alternatives for connecting with support networks that are more easily accessible to urban colleagues. Overall, rural secondary schools are also less likely to offer CS GCSEs than urban ones (Royal Society, 2017).

Conclusion

Since the DfE introduced the CS curriculum into all years at once, a child who was 5 in 2014 will be 15 and taking the GCSE in 2024. Therefore, the full impact of the mandatory curriculum change may not be visible until then. Yet, student interest in CS has grown since the introduction of the computing program of study, as indicated by GCSE participation rates.

The technology industry played a large role in initiating the computing program. This is intuitive given the industry's interest in developing a healthy pipeline of employees and that administrators and teachers do not always have enough subject matter or pedagogic knowledge. Yet, the DfE leaned heavily on industry interests when initiating the program of study in a way that disengaged teachers. This seems to have limited teaching quality (Larke, 2019). England's experience implementing CS education curriculum shows there is a sweet spot between bottom-up activity supported by teachers and top-down initiatives prescribed by the DfE, where teachers feel both supported but also empowered.

Teacher preparedness has been a challenge ever since the DfE introduced the computing program of study in 2014. Primary school teachers appear to deemphasize the program (Larke, 2019), while CS specialists can often find more lucrative careers outside of the teaching profession (Sibieta, 2018). The Network of Excellence began with only modest funding and consistently missed teacher training targets. When the Royal Society (2017) released "After the Reboo*t*," which described the poor state of teacher qualification, it was clear that the DfE could have been more ambitious with teacher training from the beginning. More funding may be needed to allow teachers time to spend on PD. Further, the Royal Society (2019) concludes that more research is needed to find effective recruitment and retention strategies.

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