Computing Education Research in the UK & Ireland

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1 Introduction

The December 1970 SIGCSE[1] Bulletin [149] published a member listing recording three members in England, and one each in Scotland and Wales. By 1983, there was at least one member in Ireland [160], and by 1995 these infrequently published

[1] The Association for Computing Machinery (ACM) Special Interest Group on Computer Science Education (SIGCSE) was founded in 1969: sigcse.org/about.

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member listings recorded at least one member in Northern Ireland [225]. Well before then authors in all of these countries had contributed to the growing volume of computing education literature.

In this chapter we present the context of Computing Education Research (CER) in the UK and Ireland, and to examine how the context has shaped the content of that research. The rest of the introduction sets the broad context, including the geographical and political scope and the major CER activities and structures. Section 2 then explores the early history of the discipline here, from the very earliest of days of computing and computing education. Like a group of siblings, for those outside the family there is a strong resemblance between them, but within the family we are perhaps more inclined to notice the differences. Therefore, in the following Sect. 3 we explore the variety within the nations and the different stages of education, in terms of the education systems, and in particular computing education, and other factors that have influenced the development of CER. Having seen where and how the CER community has been formed, we then move on to examine its outputs in Sect. 4, through a scientometric analysis of CER papers produced by authors from institutions in the UK and Ireland. Lastly Sect. 5 discusses our findings and looks towards the future.

1.1 The British Isles

The British Isles are comprised geographically of the islands of Great Britain and Ireland and thousands of other smaller islands. Politically these isles comprise the United Kingdom of Great Britain and Northern Ireland (commonly referred to as the UK), and Ireland (commonly referred to as the Republic of Ireland in this context), along with several smaller entities such as the Isle of Man and the Channel Islands that are largely self-governing. Great Britain itself is comprised of the countries of England, Scotland and Wales. There are five countries with populations over 1 million in the British Isles: England (56m), Scotland (5m), Wales (3m), Northern Ireland (2m), and Ireland (5m), with the first four all being part of the UK. Ireland has been an independent country since 1922. Education within the UK is devolved, with each of the four constituent nations having separate systems and distinct approaches to policy-making [101]. This results in five different, independent, yet broadly similar educational systems in the British Isles.

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1.2 CER Activities and Structures

In 1998, the third ACM *Innovation and Technology in Computer Science Education* (ITiCSE) conference was held in Ireland. Since then, the countries in the British Isles have worked together in advancing computing education regionally and globally (including major national curriculum and qualifications reforms), hosting numerous ITiCSE and *International Computing Education Research* (ICER) conferences and spawning several influential research projects and groups. The ACM-affiliated Workshop in Primary and Secondary Computing Education (WIPSCE) was held in England in 2015 and Scotland in 2019. The last decade has seen the establishment of two new local annual conferences: the conference in Computing Education Practice (CEP), now in its seventh year; and the UK and Ireland Computing Education Research conference (UKICER), now in its fourth year. In 2022, Ireland again hosted ITiCSE (the 27th) and for the first time hosted UKICER.

The average SIGCSE membership for the decade 2010–2019 for the UK was 53, representing just over 2% of the total membership while Ireland was 8, representing just over 0.25% [26]. Despite these relatively small number of registered members, most of whom are likely researchers, from 2010-present, the UK has contributed 362 outputs to SIGCSE venues. In 2018, the UK & Ireland ACM SIGCSE Chapter was established out of the community that grew around the Computing Education Practice conference. In 2019, driven by the establishment of several Irish university-based computing education research groups, and particularly the establishment of Computer Science as an official national Irish school subject, the decision was taken to split the UK & Ireland ACM SIGCSE Chapter into two—the UK ACM SIGCSE Chapter and the Ireland ACM SIGCSE Chapter. To date, these chapters currently have over 250 members. These chapters work closely and today co-sponsor the UKICER conference. The UK chapter focuses mainly on tertiary education because Computing At School (CAS) (see Sect. 3.1.1) already existed to support computing education in schools across the UK, whereas there was no such body to support schools in Ireland. To identify the foundations of the CER community here, we now look at the historical perspective.

2 History: Formation of the CER Landscape

British computing historian Simon Lavington argues that individuals have an inclination to consider computing history either from a bottom-up or top-down viewpoint [138]. Bottom-up, in the sense that progress bubbles-up from academics devising theories and conducting experiments in response to their peers and the scientific community. Top-down, in the sense that industrialists and policymakers allocate funding through a lens of economic development, national defence and educational attainment. Lavington suggests the best insight in terms of how things developed, is somewhere in-between. The actions and thoughts of countless individuals, organisations and structures reacting to the culture and environment of the time.

Similarly, any conversation or discussion around the present landscape of computing education research in the UK and Ireland must be situated in, or oriented around, the history of the domain in the region. An appreciation of *some* of the trends and milestones that shaped the direction of the domain is important as to provide insight into the emergence of the terrain of computing education research. An important aspect to consider is the source and motivation for funding of computing and computing education research in the UK and Ireland.

2.1 Pre-history: Babbage, Boole, Bletchley and Bombe

The UK and Ireland have made significant historical contributions to the advancement of modern computing, driven in part to being industrial, maritime and trading nations. The importance of maritime activity and advancement drove many initial contributions from the region in computing [68].

Prior to hardware and software solutions, computers were human [217]. The Royal Greenwich Observatory employed a relatively great number of them at the time to produce the British Nautical Almanac. The nautical almanac or "Seaman's Bible" contained any number of mathematical tables that were used by seafarers and others to efficiently and effectively navigate the globe [67]. The accuracy of the astronomical tables very much relied upon the human computers that generated them [66].

The British Victorian polymath Charles Babbage argued that astronomical tables, and many such others, that modern industry relied upon could be computed far more efficiently and accurately, *mechanically*, an idea endorsed by the British Astronomical Society and subsequently funded by the UK Government. Babbage devised and engineered the *Difference Engine* over 10 years. Nevertheless, after 10 years of financial support and no working system, the UK Government withdrew support [112]. Unswayed, Babbage embarked on the design of his second system, the *Analytical Engine*, and spent 15 years producing over 300 engineering schematics for a system that never materialised in his lifetime [106]. Babbage worked closely with Ada Lovelace, who is often credited as being the first programmer, through her publication of an algorithm to calculate Bernoulli numbers [110], designed to execute on the Analytical Engine. She also had a broader vision of the applicability of computers beyond solving mathematical problems, including music and graphics.

Around this time, Babbage encountered George Boole, the first Professor in Mathematics at Queen's College, Cork Ireland. Babbage and Boole did not collaborate on any of the *Engines* but Boole would go on to introduce Boolean Logic, a contribution that to the fundamental foundation for digital electronics and programming languages [32, 33]. Nevertheless, a century later, further UK

Government funding in the form of the UK Government Code and Cypher School (GC&CS) and Alan Turing resurrected Babbage's engine as the Bombe at Bletchley Park, a specialised system designed to support in the deciphering of encrypted messages used by German forces in World War II [63, 218].

Turing joined the National Physical Lab (NPL) after the conflict and started designing a general purpose computer, advancing on the specialised Bombe that was focused on deciphering codes. The eventual system was known as the Automatic Computing Engine or ACE. ACE construction completed after Turing had left the NPL and the system executed its first program in 1950. The system was refined and commercialised by the English Electric Company as the Digital Electronic Universal Computing Engine (DEUCE) and sold for approximately £50,000. A total of 33 systems were manufactured, installed and employed by universities, industries and government.

The first computer laboratory in Scotland was established at the University of Glasgow with the DEUCE at the centre. Similarly, the UK Government Department of Scientific and Industrial Research in Glasgow was equipped with a DEUCE [62]. John Womersley who led the ACE project also recognised the need for a more inexpensive and accessible version of ACE for industry and worked with Andrew Booth to produce the Hollerith Electronic Computer (HEC). The Irish Sugar Company took delivery of one of the first HEC systems at the cost of £33,000 to calculate invoices for sugar beet producers.

It was not only hardware where the UK and Ireland were making contributions. Alick Edwards Glennie worked with Alan Turing on a number of projects and worked at the Atomic Weapons Research Establishment (AWRE) in Cardiff, Wales. Donald Knuth argues Glennie, along with others such as Grace Hopper, were responsible for the first computer compilers [133].

The importance of the aforementioned milestones and contributions is not to argue ownership or suggest the UK and Ireland made exclusive contributions to computing. Many countries and continents made early and significant contributions to computing, that are often under reported and represented [44]. However, the UK and Ireland clearly did perceive computing as powerful and worthy of significant investment. The assumption would be then, just as the region had invested before, it would do so again in the education of its people in utilising such scientific advancement and achievement. Moreover, a reasonable expectation may be that energy and research funding would be spent on trying to understand effective computing education. However, as the reader will come to observe, the focus of such funding is not always obvious or intuitive.

2.2 Mind the Gap: The British and Irish Retreat

The 1960s and 1970s represented a great economic resurgence for the UK and Ireland as they engaged and participated in the global boom that occurred after the Great Depression and Second World War. The UK and Ireland were still making significant contributions to the advancement of computing in the decade. The Altas Computer, one of the world's first supercomputers, pioneered ideas such as virtual memory, paging and one of the world's first modern operating systems [139]. The system was developed in partnership between academia and industry. Nevertheless, the commercial and industrial computing influence and contribution began to retreat and recede for the region.

The leading British catering company J. Lyons and Co, commissioned the first computer for commercial purposes [135]. The company initially contributed funds to Douglas Hartree and Maurice Wilkes to accelerate their work on the Electronic Delay Storage Automatic Calculator (EDSAC) at the University of Cambridge in advance of funding their own system based on the outcome of the project. Despite, such commercial beginnings for computing in the region, by the 1960s and 1970s it was limited in contrast to the United States as was influence of the region [137].

A partial explanation for this is the contrast in differences between the gap that existed between defence research and commercial endeavours in computing in the UK and United States [136]. In the United States, there was tighter integration and collaboration between parties with the resulting benefits, whereas in the UK there was tighter secrecy and looser connections. As a result, the UK did not reap the same benefits or influence. Frank Cousins, Minister of Technology, announced the formation of the National Computing Centre (NCC) in 1965 with the aim of ensuring the society and business could realise the practical benefits of computers. The NCC funded two universities, Imperial College London and the London School of Economics to address the gap in research and education for the applied use of systems [136].

Despite such investments, the reality was the United States remained far more influential in computing at this point and as a consequence so did its research and investigation into computing education. Guzdial identifies two streams of activity in the 1960s and 1970s [109]: the psychology of programming (driven by industry); and learning of programming in schools. This characterisation was largely true of early work in the UK and Ireland.

Evershed and Rippon argued that the significant investment made by the UK and Ireland in computers in industry, research and government operation would be wasted unless there was recognition that the infrastructure could not be effectively utilised by anyone other than programmers and coders [87]. They argued that high-level languages were required for "low-level users", that in order for professionals to utilise machines, programming their calculations needed to be more efficient than those that could be done by hand. Evershed and Rippon stated that a programming language that supported individuals in minimising errors and was easy to comprehend would not be possible without appreciation of human factors. Similarly, Sime, Green and Guest performed an empirical evaluation of conditional constructs between languages as to determine what would be optimal for "low-level users" [203]. Their work, and the work of others in the UK and Ireland represented the beginnings of a rich community of researchers and practitioners that resulted in the Psychology of Programming Interest Group (PPIG)[2] and the Empirical Studies of Programming series (ESP) [30].

There were a number of different initiatives that received funding both in terms of software and hardware [180]. The National Development Programming in Computer Aided Learning (NDPCAL) was one of the earliest significant funding programming for exploring the use of computers in education within the UK. The programme funded a number of initiatives, £2.5 million spent over 5 years on 35 projects, across a number of contexts, including industry, defence training, further education, higher education as well as primary and secondary schools [117]. Similarly, the Schools Council funded the Computers in Curriculum project to support schools and teachers in developing and exchanging computer assisted learning materials. However, funding and resources were focused on *terraforming* education with computer software and hardware with little focus on the explicit value of such initiatives.

This is not to say no consideration was given to such concerns. The Nuffield Foundation, the Scottish Council for Research in Education, the Leverhulme Trust and the Social Science Research Council funded Howe and du Boulay to survey the roles of programs in education [119]. Howe and du Boulay identified: *application*, *simulation*, *drill and practice*, *tutorial* and *administration*. Identification of the different roles was significant as it demonstrates the wide spectrum of use of computers and programs. More importantly, Howe and du Boulay argued that due to the wide spectrum and potential use, educators without sufficient insight or appreciation of programs result in using them inappropriately or with negative consequence for learners. Consequently, they argued that computers had significant potential in education, but only through partnership with teachers.

2.3 Silicon Fen: Jet Set Willy and Mr Podd

The 1980s continued the focus in the UK and Ireland to utilise computing infrastructure as well as expand it. In terms of CER, focus was still on individuals making the most of computing and programming. du Boulay et al. considered how to present programming concepts to novice individuals, advocating the concept of a notional machine [34], based on the programming language to be learned rather than specific hardware. The learner learns a BASIC or LISP machine, coming to appreciate the mechanisms to solve problems and the optimal problems they can be used to solve.

Marc Eisenstadt around the same time in the early 1980s was interested in the cognitive models employed by programmers and the design of the tools the utilised. Eisenstadt proposed the SOLO programming language [83] that was designed in part to make the underlying virtual machine explicit and visible to the user [169].

[2] ppig.org.

He devised the language to support students enrolled at the Open University on a cognitive psychology course that had to complete some programming. SOLO was devised with the idea that students (a) did not want to learn programming, (b) they were working remotely in various environments, (c) they did not have significant time to spend on such learning and (d) were not computing literate. It attempted to address these issues in various ways and the benefits of the approach were investigated by researchers.

The Computer Literacy Project (CLP) emerged from the Continuing Education Television department at the British Broadcasting Corporation (BBC) [6]. The foundation of the project was informed by a commissioned report on Microelectronics from Albury and Allen [2]. The aim of the CLP was to prepare British and Irish society so that it could steer technology rather by steered by it [31] and it was designed around successful approaches adopted by a similar BBC Adult Literacy Project. The BBC adopted a mixed economy approach to computing, embracing academia, vocational and cross curricula [103]

Kenneth Baker MP after witnessing the development of computer systems and software in Japan devised a manifesto for technology in the UK with one of the aims being a single computer in every school. Prime Minister Margaret Thatcher appointed Baker as Minister for Information Technology and when the UK was experiencing a deep economic recession in the early 1980s, Baker stated that he gave "*Margaret something nice to say*", which was getting a single computer into every school. Consequently, the Department of Trade and Industry for the UK worked with BBC Engineering to specify the BBC Micro that would later be engineered and manufactured by Acorn computers.

Subsequently, Kenneth Baker devised and deployed the Microelectronics Education Programme (MEP) and Scottish Microelectronics Development Programme. The programmes built on the NDPCAL investment of the 1970s, but with specific focus on schools [224]. Broadly the programmes can be considered as having two territories—(1) using computers in the most effective ways across the existing curricula and (2) introduction of new curricula for such systems: information retrieval, scientific instruments and control technology [100, 104]. The programmes drove widespread deployment of hardware and software into schools, but the programmes were widely criticised for deploying resources without sufficient consideration as to what was optimal for the domain of education. Fothergill, programme director, discussed the balance and challenge of research and deploying computer systems [99]. The challenge or concern was that by the time research delivered results, things would have changed. However, the Social Science Research Council planned a programme of research into microelectronics in education [104].

The concerns around education and the deployment of computers into schools is likely crystallised by the Mr Podd debate. Mr Podd is a character in software that children could instruct various actions, such as *walk* and *run*. A list of actions is not provided to children or teachers as an explicit part of the motivation for children is to learn and engage with vocabulary to get Mr Podd to perform various actions. Thorne argues that despite teachers considering the Mr Podd the best educational software of 1984, the software solution was not borne out of any research or evaluated in terms of effectiveness [212]. O'Shea and Self, as emphasised by Thorne, argue that research is required both in deploying software and assessing it in terms of its relevance to education [176].

The early 1980s represented a period of excitement and innovation around personal computing with many consumers purchasing the Sinclair ZX Spectrum, the Acorn, BBC Micro and Commodore 64. However, while the personal computing market was vibrant it collapsed within a few years and while there may have been many visions of computers and education, many of the systems were used to play games [140]. The legacy of the movement in the UK was successful at least in terms of the economy and innovation. The City of Dundee became a destination for games development, a history that can be traced back to the production of the Sinclair ZX Spectrum in the Dundee Timex factory [154]. Acorn subsequently developed their own RISC architecture, the Acorn RISC Machine (ARM) which subsequently became known as Advanced RISC Machine and spun off through Arm holdings, now know simply as "Arm", one of the most valuable tech companies in the world.

The period of the 1960s through to the 1990s represented significant investment in computing and education. However, there was less interest, focus or appreciation of the importance of computing education research by policy and law makers. Despite appreciation for the significance and potential for computing by such individuals, there was less concern about refining the methods and infrastructure around computing education. The early computing education research efforts in the UK and Ireland tended to happen around the edges of funded projects or were driven by the interest of a few dedicated individuals.

2.4 Devolution: Things Can Only Get Better for Education and Research

The 1990s did not represent a decade of significant change in the status quo for computing education research in the UK and Ireland. The region had spent considerable resources on computing in the decade prior and it was not clear how it was benefiting from it. However, the 1990s did represent a significant shift in governance for the United Kingdom, that would go on to shape computing education research, in the form of devolution.

In 1999, many significant elements of UK governance in terms of law, management of public services and spending priorities were devolved to institutions in Scotland, Wales and Northern Ireland away from the central UK parliament. The significance of the experiment, depends on the region. Scotland had strong public support and specific ideas whereas the public and politicians in Wales and Northern Ireland were still developing their own perspectives on powers [54]. England, with the biggest population, and Ireland, the neighbouring independent country, were largely unaffected by devolution.

The decisions taken in the different regions are best considered through the lens of *convergence* or *divergence* of governance and approach [102]. The potential impact for computing education from devolution is that the different regions could (1) adopt different approaches to research funding as well as (2) adopt different spending priorities. For example, Wales may diverge initially on some aspects, only to converge on the same approach that are adopted in England later.

In terms of general research funding, allocation of public funds is broadly determined by the Research Excellence Framework (REF), an evaluation that is completed across the UK. Higher Education Institutions are evaluated in terms of research quality and with resources allocated favouring those institutions that produce high-quality research. Strategically, the different regions adopted different approaches to the allocation of actual resources with England allocating based more on quality whereas Scotland and Wales favoured spreading resources more between their institutions. However, over time both Scotland and Wales have converged to adopt a similar approach to England.

Scotland in particular favours research pooling and initiatives to motivate institutions collaborate together. The strategic approach has been successful for Scotland, research impact for Science Technology Engineering and Mathematics in particular has been significant. Scotland also over-performs in securing research funding from the UK Research Council [129]. The Scottish Informatics and Computer Science Alliance (SICSA)[3] is an example of one such research pool. SICSA was launched with £14.5 million from the Scottish Funding Council and supported appointment of 30 academic members of staff across Scottish institutions to improve the research quality of computing science in the region. SICSA was unique as a research pool as its remit was extended beyond research to include education. However, the direct impact of such an expansion on specific computing science education research is less clear.

The other aspect of devolution that has the potential to shape computing science education is spending priorities and initiatives, specifically in school education. Different approaches to computing science education in schools can result in individuals being able to conduct research around the edges of such initiatives. England and Ireland were not impacted directly by devolution, but are *indirectly* impacted by the actions taken by other nations. If Scotland spends more on computing education research, for example, it is unlikely neighbouring nations can simply ignore it—especially if such a decision is successful or reaps significant benefits. Consequently, nations can *converge* on solutions and policies, if they prove optimal in different settings. In terms of the specific impact of devolution, it is how the nations diverge that may lead to interesting outcomes [43], and is the differences between nations that are the focus of the next section.

[3] www.sicsa.ac.uk.

3 Computing Education Research Context

Section 2 demonstrated some of the central trends and milestones that informed the present-day computing education research context in the UK and Ireland. Here we outline how recent developments have differentiated the computing, education and research contexts of each of the nations.

3.1 England

We separate our presentation into a consideration of compulsory school education (referred to elsewhere as K-12) in Sect. 3.1.1 and post-compulsory education in Sect. 3.1.2.

3.1.1 Schools in England

England has a long history of computing in school dating back to the 1970s and 1980s [42, 46]. Personal computers such as the BBC micro and ZX Spectrum in school, the use of Logo in mathematics to teach coding, and schools examinations at approximately 16 and 18 years of age (called GSCE and A-Level) in Computer Science or Computer Studies dating from the 1970s [46] all meant that there were opportunities for *some* children to learn some computer science and programming.

A significant change came to England when the Education Reform Act 1988 defined what all children should learn and the concept of a National Curriculum was born [226]. In 1988 a National Curriculum was introduced for schools in England (and initially Wales until devolution in 1999), through the Education Reform Act. The National Curriculum established information technology within the curriculum which needed to focus on building basic computer literacy skills, although it did touch on some aspects of computer science:

> *"While it is not envisaged that all pupils would undertake the detailed study of a programming language they should understand the concept of a computer program as a set of instructions. This understanding can be promoted by the use of certain drawing or control packages where a sequence of moves can be 'saved up' and executed together. The contribution of particular instructions to the whole can be examined without discussing in detail the underlying algorithm. Some pupils will have acquired a detailed knowledge of programming by using computers at home or by specialist study at school."* [114, p.26]

The Dearing review [73] led to an overhaul of the National Curriculum with a new version published in 1999 [122]. Information and Communication Technology (ICT) was statutory in schools for all children 5–16 (Key Stages 1 through to 4) from 2000 [77] but it was difficult to find any aspects of computer science in it. What this curriculum did was move the focus to an ICT literacy for all students, away from principles of computer science. A revision of the curriculum in 2007 did not change this focus, and so, within a few years of that, we began to hear a call to bring back the "computer studies" element which had been lost from the curriculum [64].

The transition from ICT to Computing in the curriculum in England has been well documented and was informed by CER [42, 43, 222]. England introduced a new computing curriculum to schools in 2014, bringing mandatory computer science to all state-school pupils aged 5–16. The Royal Society, through an influential report, had redefined computing as having three elements: information technology, digital literacy and computer science [210]: this was a useful distinction to aid in this transition but is now outdated. At the time of writing, England has 7 years of experience of the implementation of computing in school, which has presented both exciting opportunities and some tough challenges.

Creation of a National Centre for Computing

In 2018, following another Royal Society report describing computing in England as "patchy and fragile" [211, p.6], the Department for Education in England awarded a contract for over £80 million for a 4-year programme of development of teacher training and student resources in computing, called the National Centre for Computing Education (NCCE) [199]. This represented one of the most substantial moves towards educating all children in the discipline of computing in the world. The NCCE provided professional development for almost 30,000 teachers in its first 2 years of delivery[4] and has enabled full curriculum resources, support on pedagogy, and a comprehensive in-service teacher education offer to be provided, free of charge to teachers. England is one of the only countries that provides mandatory computing in the curriculum for all children from age 5 upwards [222].

A recent report by the Brookings Institute comparing computer science education around the world highlighted seven policy actions that a country should undertake to bring computer science to young people effectively [222] with England being the only country to have implemented them all. These include: introduction of ICT education programs; requirement for CS in primary education; requirement for CS in secondary education; introduction of in-service CS teacher education programs; introduction of pre-service teacher education programs; availability of a specialised centre or institution focused on CS education research and training; access to regular funding allocated to CS education by the legislative branch of government. England has undertaken all these policy actions which has made it a useful comparison point for many other countries wishing to introduce CS into the formal school curriculum [222].

Focus on Delivery: Not Pure Research

Throughout this period, developments in England have been facilitated by different stakeholders working together to advocate for the importance of computing in

[4] static.teachcomputing.org/NCCE_Impact_Report_Final.pdf.

school. Computing At School (CAS) was set up in 2008 [42] and brought together industry, academia, education professionals and schools to campaign for a more CS-focused curriculum [43]. The current large-scale initiative in computing education, the NCCE, is run by a consortium of three organisations, the BCS, of which CAS is a part, the Raspberry Pi Foundation, and Stem Learning, showing the importance of collaboration and involvement of multiple stakeholders. However the characteristic of developments in England are that while considerable funding has been made available for delivery of professional development and creation of resources, there has been no corresponding funding for computing education *research*, and even rigorous evaluation of the aspects of the programme has not been a priority for the government. This could be seen as a lost opportunity given the huge numbers of young people currently studying computing in school on a daily basis in England, and there is an urgent need to understand better how and what to teach. Steadily the numbers of individual researchers and doctoral students studying computing education for young people have started to grow in England, but without a significant pot of funding. This is in contrast to, for example, the US, where the NSF and other statewide initiatives have provided specific and generous funding avenues for K-12 CS Ed research over the last 5 years.

3.1.2 Further & Higher Education in England

Further Education: The Cinderella

Within the UK and Ireland, Further Education (FE) is understood as post-school education which is not Higher Education (HE) i.e. it doesn't lead to the award of a degree—similar to continuing education in the USA or TAFE in Australia. The focus of FE colleges is in vocational training, including apprenticeships, and also in access courses for HE, with returners to education an important focus. FE is often referred to as a "Cinderella" service that, according to the influential 2018 Augur Review of post-18 education in England [9], has suffered "decades of neglect and a loss of status and prestige amongst learners, employers and the public at large" . . . "despite widespread acknowledgement that this sector is crucial to the country's economic success". Sadly, this neglect carries over into the realm of Computing Education Research, with very little attention focused on FE.

Universities in England

Higher education (as we now call it) in England started in 1096 at Oxford, followed by Cambridge in 1209, making them some of the most ancient universities in the world. There were no more new universities in England from then until the 1830s, with the founding of Durham and London universities. The start of the twentieth century saw large scale expansion in the "red brick" civic universities in Birmingham, Manchester, Liverpool, Leeds, Sheffield and Bristol between 1900 and 1909. Another group of universities were founded in the post-war period 1948–1957, developing from local university colleges working towards exams from London University. The 1960s saw a further doubling of the number of universities, some based on existing institutions, but many (the "plate glass" universities) were entirely new, starting with the University of Sussex in 1961 and culminating in 1969 with the Open University, the UK's only university dedicated to distance learning—and having by far the largest student enrolment. The last step change in the number of universities came in 1992, when nearly all of the existing polytechnics became universities in their own right, having previously used the degree awarding powers of the Council for National Academic Awards (CNAA). These "new" or "post-92" universities developed research interests where they previously had mainly focused on teaching and with that developed a much stronger academic community exploring subject-specific pedagogy—such as CER. The twenty-first century has seen a steady stream of institutions newly gaining university status.

Quality and Funding of HE Teaching

The vast majority of English universities are public, in that they receive some funding from the government. One of the main differences in policy for universities in different parts of the UK relates to funding. From 1962 to 1998 full-time students were exempt from tuition fees, and also had access to a means-tested maintenance grant. Following the Dearing report [72] (not to be confused with the 1994 Dearing review of school curriculum), student fees were introduced, along with a system of government-backed loans for paying these fees, and for covering living expenses of students (maintenance loans). The level of these fees increased over time to a maximum of £9250 currently, as universities have become more dependent on student fee income as opposed to direct funding of teaching through the Higher Education Funding Council for England (HEFCE) and then the Office for Students (OfS) since 2018. From 2000 the HE sector has become increasingly marketised, although there is virtually no differentiation on price between institutions—the competition has really been on attracting student numbers. Established in 2005, the National Student Survey (NSS) has been an important metric for universities, very often used in published league tables. It provides half of the data points for the Teaching Excellence Framework (TEF), first introduced in 2017. However this has been far from controversial, with the National Union of Students (NUS) at one stage voting to boycott the NSS because of the link to TEF and marketisation of HE.

There is stark contrast between policy, and to some extent research interest, on education in schools and universities. Schools are tightly managed on the academic performance of their students in public examinations, and in particular on the progress they make. In universities, the focus is much more on customer (student) satisfaction and on graduate employability. Indeed, the idea of "learning gain",[5] the HE equivalent of progress measures in schools, is considered experimental and controversial, certainly within the context of TEF. Universities are therefore not incentivised to ensure their students learn a lot, but rather to make them satisfied and employable. Standards within degrees are monitored by the Quality Assurance Agency (QAA), commissioned by the Office for Students (OfS), along

[5] www.officeforstudents.org.uk/advice-and-guidance/teaching/learning-gain.

with the system of external examiners (first used by Durham University to ensure comparability with Oxford), but the issue of "grade inflation" has become an important one.[6] Even aside from the maintenance of standards, educators are often concerned with assessment, not least because scores for Assessment and Feedback are usually amongst the lowest of all the measures within the NSS.[7] For these reasons it is typically much easier for educators to analyse and report on anonymised student opinion of teaching, through module evaluation questionnaires designed to mimic the NSS, than looking at individual student understanding or progress.

Quality and Funding of HE Research

UK Research and Innovation (UKRI), which took over research funding responsibilities from HEFCE, allocates research funding to universities on a recurrent formula basis through Research England and also through competitive grant funding awarded by the research councils. A large portion of the recurrent funding to universities is quality-related (QR), as identified by the UK-wide Research Excellence Framework (REF), previously known as the Research Assessment Exercise (RAE). The research outputs (typically papers), impact and research environment of a university are assessed by panels covering different Units of Assessment on a semi-regular basis, with the most recent assessment points in 2021, 2014 and 2008. The issue for CER is that there are separate REF sub-panels for "Computer Science and Informatics" and "Education", so there is no natural home for CER research to be assessed: papers might be seen as "not real computer science" by one panel and "not real education" by another.

A similar situation exists within the funding councils that award research grants. Computing research (termed ICT: "information and communications technologies") falls within the remit of the Engineering and Physical Sciences Research Council (EPSRC) whereas education comes under the Economic and Social Research Council (ESRC). Although they have similar acronyms, they are very distinct, and neither funds computing education research projects.

Overall this leads to a research context which is largely unfunded, and based on the interests of practitioners. Sometimes industry has funded CER in England, notably the BlueJ project [134] largely funded by Oracle. This project was led by Michael Kölling, one of two England-based recipients of the SIGCSE Award for Outstanding Contribution to Computer Science Education. Despite substantial industrial funding, BlueJ never received government research council funding. Sally Fincher, the other recipient of the SIGCSE Outstanding Contribution award also never received any government research council funding, despite major contributions including the Cambridge Handbook of Computing Education Research [95]. None of this was for want of trying, but rather because the funding councils did

[6] www.officeforstudents.org.uk/news-blog-and-events/press-and-media/grade-inflation-remains-a-significant-and-pressing-issue-new-ofs-analysis.

[7] www.officeforstudents.org.uk/advice-and-guidance/student-information-and-data/national-student-survey-nss/nss-data-overview.

not consider it within their remit. The EPSRC has awarded grants for outreach and engagement within computing [84, 85] but not for pedagogical research directly.

Focus on Employability

Employment prospects for graduates are a key measure for success of HE courses, being routinely included in published league tables and TEF scores. One particularly paradoxical issue for computing degrees has been the reported shortage of skills in graduates, relatively low popularity of the subject area and high rates of unemployment amongst computing graduates. This issue was addressed in the influential Shadbolt review [201] of computer science degree accreditation and graduate employability, which found that "the supply of Computer Sciences graduates, and the needs of employers appears in some way misaligned". A complex range of factors came into play, and recommendations included: extending work experience; improving graduates foundational knowledge and softer skills; better understanding the needs of startups and SMEs; better engagement with accreditation by both industry and HEIs.

The UK Government introduced the Apprenticeship Levy in 2017. The levy required employers with an annual pay bill that exceeds £3 million pounds to pay an additional 0.5% levy or tax on their pay bill. The levy is then transferred to an account and supplemented with additional 10% contribution from the UK Government. Employers then have 24 months to spend the funds in their account on appropriate training programmes. This, combined with the introduction of degree-level apprenticeships, has led to many new computing degree programmes based on the apprenticeship model of work experience and part-time study, and in turn to CER in the area of curricula and pedagogy for apprenticeships, quite distinctive to the UK (although related to the idea of cooperative education in the USA [120]). Universities have also engaged with the Institute of Coding, a "collaborative national consortium of industry, educators and outreach providers" established in January 2018, with £20 million in funding from the Office for Students. As with government initiatives in schools, these do not directly fund CER, but CER often naturally follows this kind of funded activity.

3.2 Northern Ireland

With the introduction of the Good Friday Agreement in 1997, a devolved administration in Northern Ireland (NI) had now two Ministers of Education—one with responsibility for the school sector and the other for further and higher education. The Good Friday Agreement provided a North-South Ministerial Council to discuss educational matters of interest between Dublin and Belfast. Practically, policy would either take into account UK directives but interpret and apply these around the special circumstances in NI, or be driven by NI's particular needs [198]. The Department of Education for NI (DENI) aims to promote the education of the NI people to ensure the effective implementation of education policy. DENI are now supported by this one non-departmental sponsored public body CCEA. CCEA is NI's educational awarding organisation for a range of qualifications. As part of this they advise the DENI on matters concerned with the curriculum.[8]

3.2.1 The Northern Ireland Curriculum

Northern Ireland's constitutional position in UK has meant that government policy in education in Northern Ireland has often followed initiatives taken by the Department for Education in England and Wales. The statutory curriculum in Northern Ireland began with the Education Reform Order in 1988. This stated the curriculum for a grant-aided school included Science and Technology.

The curriculum itself was introduced from 1991. Shortly after, statutory teacher assessment began at the end of Key Stages 1 (Year 4) and 2 (Year 7), mainly for English and Maths. It was found in practice to be overloaded, so in 1996 it was significantly revised removing a large amount of content but unchanged in structure. In 1999 the then Education Minister gave permission for The Council for the Curriculum, Examinations and Assessment (CCEA) [53] to undertake a fundamental review of the statutory requirements of the curriculum. Evidence within this review of primary school showed that within NI there are well documented differences between high and low attaining children linked to social deprivation and to gender [53]. Data gathered from young people in NI showed that ICT was top of their agenda [198].

The resulting 2002 curriculum proposals focused on a range of skills including critical and creative thinking skills, including managing information, problem solving, and ICT. The revised Northern Ireland Curriculum was introduced in 2007 and implemented over a 3 year period, covering all 12 years of compulsory education.

The DENI's empowering Schools Strategy for ICT [219] focused on transforming education by 2020 with strategic deliverables for 2008. The overarching aim of this strategy was "that all young people should be learning, with, through and about the use of digital and online technologies". The strategy's key focus was the deployment of digital, multimedia and communication technologies to "enhance, improve, and ultimately to transform, education".

While ICT is included in the curriculum as a cross-curricular skill and relates to using software in school, schools have some flexibility to include teaching coding. However, there is evidence that coding is rarely taught in primary schools or key stage 3 [181]. CCEA introduced the A/AS level in Software Systems Development in 2015/16, the A/AS level and GCSE in Computing in 2017 and Digital Technology in 2018.

In 2021, Calder [49] provided a British Computer Society (BCS) landscape review on computing qualifications in the UK. In NI, ICT remains the main

[8] www.legislation.gov.uk/nisi/1998/1759/contents/made.

qualification of computing education across key stage 4 and post-16. However, there has been growing uptake of A-Level Computing. The last 5 years have seen a drop of around 50% in ICT entries for all qualification levels being replaced with growth in Digital Technology topic. A/AS level in Software Systems Development (SSD) has seen a decline in uptake since it became part of the curriculum, with just over 200 students taking this in 2020/21. Female: male participation rates show ratios of 1:2 studying ICT, 1:9 in GCSE computing and 4:1 at A-Level. In 2018–19 A-Level computing's popularity as one of the nine STEM subjects remains second least popular and in 2020–21 only 3% of A-Level cohort taking computing.

Matrix (NI Science Industry Panel)[9] commissioned a positioning paper in 2018 on Women in STEM in NI. The issue of STEM skills shortages continues to be prioritised as a barrier to growth in NI science and technology sectors. This work highlighted the continuing significant gender imbalance across the STEM skills pipeline as a major contributing factor. In 1999, 11,943 boys and 11,104 girls were born in NI, in 2014/15 87.6% of the girls took STEM GCSEs, compared to 91% of the boys. However, when it came to core STEM A-levels or FE vocational exams in 2016/17, only 31% of girls took one, in stark comparison to 85% of boys who took one. For NI futures the decline in girls participating in STEM between GCSE and A-level/FE is anticipated to be 65%, compared to a 6% drop off for boys.

3.2.2 Higher Education in Northern Ireland

NI has three universities (Queens University, Ulster University and Open University), two university colleges (St Mary's University College, Stranmillis University College), six further education colleges (Belfast Metropolitan, Northern Regional, Southern Regional, South Eastern, North West Regional, South West), and College of Agriculture, Food and Rural Enterprise (CAFRE) an agri-food and land-based college with 3 campuses, all of which offer opportunities to study for various higher education qualifications.

To try to meet the growing needs of NI's computing industry in 2010, Queens and Ulster designed and offered a one-year conversion masters to students who had completed a non-computing undergraduate course. These courses were immediately very popular, particularly with females, and employment figures for the graduates were very high.

3.2.3 Growing Computing Opportunities in NI Moving Forward

In May 2021 DfE published their new economic vision for NI for consultation.[10] It sets out the key themes and proposed commitments for a new Skills Strategy for

[9] matrixni.org/wp-content/uploads/2018/05/Women-in-STEM-Report-final-20-may.pdf.

[10] www.economy-ni.gov.uk/publications/10x-economy-economic-vision-decade-innovation.

Northern Ireland: Skills for a 10× Economy. The Strategy sets the strategic direction for the development of Northern Ireland's skills system to 2030. The primary challenge for Northern Ireland is to increase the number of individuals entering the labour market with qualifications in STEM, particularly in the "narrow STEM" fields: physical, environmental and computer sciences; engineering; and mathematics. Other projects feeding into this strategy are: joint DE/DfE "Transition of Young People into Careers (14–19) Project"; challenges in understanding and addressing declining participation in level 4 and 5 education[11] with the ongoing work on the review of HE in FE; and an "Independent Review of Education", announced by the Minister of Education in December 2020. One of DfE's strategic goals for the new Skills Strategy includes increasing the proportion of individuals leaving Northern Ireland higher education institutions with degrees and post-graduate qualifications in "in-demand" STEM subjects, including computer sciences.

Following the popularity of the MSc conversion courses, funding from the Northern Ireland Office and the Department of Finance offered support to a wide range of free short courses, delivered by the local FEs and HEIs. DfE have already funded up to 7000 free places, with many more to come.[12] Courses are offered on a range of digital skills including: applied cyber security, artificial intelligence, computer science, data engineering, data science, and software testing.

Extensive initiatives are being continually developed across NI with FE and HE providers, industry and STEM partners to grow and inspire young people at all levels to consider a future in computing, and particularly grow the number of females. These include campaigns such as Bring I.T. On,[13] engaging with partners on education policy, curriculum and content development, developing STEM engaging learning and STEM competitions with CCEA, Computing at School,[14] Matrix-NI,[15] BCS-NI[16] and Sentinus.[17]

An example of this comes from 2016 Digital ICT Report published by Matrix-NI[18] which identified four areas in which NI was already, or had the potential to be, world class: software engineering, advanced networks and sensors, data analytics and cyber security. Within this they also noted five sectors which had already been identified as key drivers of the NI economy that stand to benefit from advancements in AI. Matrix then commissioned The Alan Turing Institute to undertake a review of AI capabilities in NI. The report concluded the need for a single AI Centre of Excellence (AiCE@NI), which brings together the best of NI research and

[11] www.gov.uk/what-different-qualification-levels-mean/list-of-qualification-levels.

[12] www.nidirect.gov.uk/skillup#toc-4.

[13] BringITonNI.co.uk.

[14] www.computingatschool.org.uk.

[15] matrixni.org.

[16] www.bcs.org.

[17] www.sentinus.co.uk.

[18] matrixni.org/wp-content/uploads/2019/06/Artificial-Intelligence-Research-in-Northern-Ireland.pdf.

commercialisation, and provides a strategic focal point for internal and external NI AI activity.

In line with a recommendation from Calder [49], in 2021 BCS-NI supported a new committee BCS: Northern Ireland Computing Education Committee (BCS-NICEC) to facilitate communication between interested parties in computing education in Northern Ireland. This will include primary and secondary level school teachers, award and regulatory bodies, higher and further education staff, industry, government departments and learned societies. As part of this work BCS have also supported the formation of a Young Persons Advisory Board to enable a student voice in computing education. This group is modelled on Ulster University's Community Of Practice engaging with student groups and a model from the BCS Scottish Computing Education Committee to get young peoples input into designing and deploying methods of collecting the student voice.

3.3 Scotland

The majority of computing education research in Scotland is directed and led by Higher Education Institutions (HEIs) in partnership with schools and colleges. In the context of Scotland, 14 HEIs are active in computing science research and education as evident in membership of SICSA.[19]

Similar to other nations in the United Kingdom, Scottish HEIs have a mixture of singleton researchers focused on computing education research as well as research groups. There are a number of such research groups emerging in Scotland. The Centre of Computing Education Research at Edinburgh Napier University is focused on employability and pedagogy research.[20] The Engineering and Computing Education Research Group at Glasgow Caledonian University is focused on a number of research areas, including assessment design and feedback.[21] The Centre for Computing Science Education at the University of Glasgow[22] is led by the School of Computing Science at the institution but represents an interdisciplinary partnership between many different areas.

Scottish institutions and academics have acted as hosts, programme chairs as well as leads for doctoral consortia, works in progress workshops and working groups for a number of leading computing education venues. Venues include the Innovation and Technology in Computer Science Education (ITiCSE) conference[23] in 2019,

[19] www.sicsa.ac.uk.

[20] www.napier.ac.uk/research-and-innovation/research-search/centres/centre-for-computing-education-research.

[21] www.gcu.ac.uk/aboutgcu/academicschools/cebe/research/researchgroups/engineering-and-computing-education-research-group-ecerg.

[22] www.ccse.ac.uk.

[23] iticse.acm.org.

the International Computing Education Research (ICER) conference[24] in 2014, as well as the Workshop in Primary and Secondary Computing Education (WiPSCE)[25] in 2019. Similarly, Scottish institutions and academics have performed the same service for national venues including the United Kingdom and Ireland Computing Education Research (UKICER) conference[26] in 2020 & 2021, and the Computing Education Practice (CEP) conference[27] in 2022.

Academics in Scottish institutions regularly contribute to many computing education venues, including the ACM Transactions on Computing Education (TOCE) journal [81], the ICER conference [214], the British Journal of Educational Technology journal [82], the Computers & Education journal [11], the WiPSCE conference [195], the Koli Calling conference [130], the Computing Science Education journal [29] and the Technical Symposium on Computer Science Education [178]. Furthermore, some academics in Scottish institutions have made significant and notable contributions to the computing education community. McGettrick from the University of Strathclyde received the Association for Computing Machinery's Karl V. Karlstrom Outstanding Educator Award. Purchase has been recognised as a contributing author to a significant Working Group paper [150]. Similarly, Cutts has been recognised as a contributing author to a Top 10 Working Group paper [182].

Moreover, researchers from Scottish institutions have made steady and notable contributions in recent years to the computing education landscape with research papers that have received either honourable mention [125, 213] or best paper recognition [69, 124, 177]. It is clear that Scotland has a vibrant and diverse computing education research community that regularly contributes to the community.

However, beyond typical and traditional computing education research areas, it would be reasonable to argue that computing education research output in Scotland is influenced indirectly by state funded educational initiatives. That is to argue, that such state funding is often not directly targeted or related to computing education research but some other aspect of education or training, that permits research around the edges. There are two areas that demonstrate the indirect influence on computing education research outputs from national funding and initiatives after devolution in the UK.

The first area is the *Curriculum for Excellence*, the national curriculum for Scotland. Scotland's national curriculum was introduced from 2010 onward after a consultation exercise conducted by the Scottish Government. It was introduced with the aim of shifting focus away from facts and knowledge to skills and competencies. The introduction of the national curriculum was significant for computing education as it cemented the position of computing in Scottish education prior to age 14 [123]. However, there were concerns about how teachers achieve the outcomes and experiences for computing education at this early age level [148]. The national

[24] icer.acm.org.

[25] www.wipsce.org/2022.

[26] www.ukicer.com.

[27] cepconference.webspace.durham.ac.uk.

curriculum introduced an opportunity for computing education research in Scotland in terms of funding and the opportunity to integrate and investigate computing education research at scale. We consider two examples from this area, Haggis the reference programming language for national assessments, Sect. 3.3.1, and PLAN C, the personal learning network for computing teachers, Sect. 3.3.2.

The second area is *Skills in Higher Education*. Skills Education was another development devolution in the UK that afforded an opportunity for computing education research in Scotland. The UK Government introduced an Apprenticeship Levy with the aim of strengthening skills education, including in HEIs. Scotland delivered Graduate Apprenticeships (GAs) as a result and this in turn provided opportunities in funding and resources around designing appropriate software engineering programmes for higher education. We consider one example from this area, a research-informed reference design for an apprenticeship programme in Software Engineering, Sect. 3.3.3.

3.3.1 Haggis Reference Language for School-Level Assessment

The qualification authority commissioned the development of a high-level reference programming language in 2010 as the means to effectively examine computing science assessment outcomes in Scotland. The 1980s had created a diverse zoo of systems and programming languages throughout Scotland and as a consequence, educators were permitted to internally assess using their programming language of choice. Prior to the national curriculum, national assessments relied upon pseudo-code, an informal blend of formal and natural language. The approach introduced instability and ambiguity as the pseudo-code altered from year to year with each assessment. Moreover, the overall approach is focused more on writing programs rather than understanding programming language code, an approach that is sub-optimal to support learning and teaching of formal languages. Consequently, the educational rationale was to ensure a *consistent* pseudo-code that supported the assessment of programming rather than writing programs [159].

The solution was Haggis, a bespoke pseudo-code for assessment developed by computing education researchers in Scotland and tailored specific to the Scottish context. The reference language had to be adaptable to programming languages taught in the Scottish curriculum as well as be sufficiently complex to support assessment from early years to advance qualifications. The aim of Haggis was to support rigorous assessment of core computing concepts and topics with research still ongoing to determine if this is the case.

3.3.2 Professional Development of School Teachers in Scotland

The national curriculum cemented or established computing education in one form or another across school education in Scotland. The approach is not unique as many countries around the world, including the comprising nations of the UK as well as Ireland, have also prioritised the introduction of computing across school education. For example, the United States CS10K initiative aimed to have 10,000 teachers in 10,000 high schools delivering computing curriculum by 2015 [8, 40]. The task is not without concerns and just as other countries have experienced, there are significant challenges for teachers in rapidly introducing computing education [227]. The areas of particular concern are (1) professional practice and (2) pedagogical content knowledge.

For professional practice the concern is that computing educators, like many educators, are lone individuals within a school environment. Consequently, they have limited opportunity to discuss and debate their professional practice within the context of their specialised domain, i.e. computing. For pedagogical content knowledge, many computing educators within Scotland and elsewhere have a limited background in computing education. Furthermore, given the limited opportunity to discuss and debate professional practice with other computing educators in their context, they likely have weak or deteriorating pedagogical content knowledge [202].

Therefore, improving the continuing professional development of teachers is an important tool in delivering on objectives to introduce computing education across school education. Sentance at al. explored the use of community of practices for teachers [200] and Fincher et al. surveyed many different models that could form the basis of improving the professional practice of teachers [94]. Disciplinary Commons [209] is one such approach that has been used in higher education but can also be valuable for school educators.

In Scotland, the Scottish Government funded the project Continuing Professional Development for Teachers of Computing Science. The outcome was the Professional Learning Network for Computing (PLAN C). The professional development programme was largely designed around the idea of Disciplinary Commons where computing educators could meet and discuss computing research appropriate for deployment in practice, prior to use and after it. The network comprised of a number of communities of practices that spanned across Scotland guided by lead teachers. The approach required identification and training of lead teachers also using a Disciplinary Commons approach. PLAN C was subsequently evaluated and deemed to be successful with at least half of potential computing teacher candidates engaging with at least one PLAN C session. For those participants surveyed the majority deemed the solution a positive impact for teachers and students [70].

3.3.3 Scottish Industry Partnership Programmes for Higher Education

The Apprenticeship Levy, introduced in 2017, is UK wide and so is payable by all employers regardless of where they reside. However, Skills and Education is a devolved matter, see Sect. 2.4, and so the implementation of how the Apprenticeship Levy is accessed and utilised depends on the nation.

In the first year of collection, Scotland received £221 million pounds from the Apprenticeship Levy. The Scottish Government decided to fund a number of initiatives in response to the allocation of the budget, including Graduate Apprenticeships (GAs). A Graduate Apprenticeship (GA) is essentially a 48-month programme delivered in partnership between HEIs and industry partners to the eventual attainment of a degree. The GA programme is administered by the national skills agency, Skills Development Scotland (SDS). The agency provided a select number of GA specifications developed in partnership with academia and industry. Employers and HEIs then form partnerships and agree to shepherd a number of students or employees through degrees, designed to approved specifications.

The concern in Scotland, particularly for research-led institutions, was the lack of familiarity and experience in delivering apprenticeship-style education in partnership with employers in the context of higher education. Skills Development Scotland funded different research and development projects around the specifications so that industry partners and employers could further refine delivery plans.

Maguire and Cutts [146] report on one such project that researched and developed the design of a GA programme in partnership with industry to deliver professional Software Engineers. The investigation outlines research into the history of cooperative and apprenticeship-style education in the context of higher education. They also outline case studies from Germany, Ireland and Canada that involved institutional visits and interviews with stakeholders involved in the delivery of apprenticeship-style programmes in higher education. Maguire and Cutts devise a number of principles to inform the design of apprenticeship-style programmes in higher education.

3.4 Wales

Wales is a small nation to the west of England, with a rich and distinct history, grounded in a Celtic cultural identity and the Welsh language (*Cymraeg*, alongside English as one of the two official languages), with 29.1% of the population able to speak Welsh. Its south coast became pre-eminent during the UK's industrial revolution due to extractive mining and metallurgical industries, as well as associated heavy industries, transforming the country from an agricultural society into an industrial nation. Outside of the major population centres in the south and north of the country, Wales is largely rural and mountainous, and suffers from post-industrial socio-economic challenges, seasonal employment focused on the tourism industry, and the dependence on the public sector for a significant proportion of jobs. Wales also faces issues regarding inequality; almost a third of children live in poverty and its proportion of employees who are the lowest-paid is the highest in the UK. Overall, the poverty rate has been higher in Wales than for England, Scotland, and Northern Ireland in each of the last 20 years. Prior to the UK's exit from the European Union at the end of 2020, the majority of the country (apart from the south-east corner, including its capital city Cardiff, and the regions bordering England) had historically been designated by the European Union as so-called "Convergence areas", meaning the per-capita GDP was less than 75% of the European Union average, making it eligible for a range of European strategic funding initiatives, resulting in large investments in skills and infrastructure.

Education in Wales has historically developed along similar lines to that of England, with UK legislation largely having force in both countries; especially following the establishment of the National Curriculum from the Education Reform Act 1988. In 1997, Wales held a referendum which determined the desire for self-government, leading to the Government of Wales Act 1998, which created the National Assembly for Wales—to which a variety of powers were devolved from the UK parliament on July 1, 1999. In particular, education—which until then was a UK-wide government portfolio (minus Scotland, which for historical reasons, has had a distinct legal and education system from England and Wales)—came under the control of the National Assembly for Wales (now, *Senedd Cymru* or Welsh Parliament). Now, the Welsh Government has control over education policy, teachers' pay and conditions through the Welsh Parliament, although the UK Government still retains control of certain areas, such as teachers' pensions. Education in Wales has developed a distinct identity, with education policy and the wider Welsh education system increasingly diverging from policies and practices in England. This is set to continue with the major education system-level reforms currently taking place at the time of writing, including significant changes to the national curriculum, assessment and qualifications.

3.4.1 Schools in Wales

Prior to devolution in 1999, the education system in Wales was essentially identical to that in England and was in a healthy state, outperforming other regions in the UK in the years prior to and immediately following devolution. However, ever since devolution saw the education portfolio transferred to the National Assembly of Wales, it has suffered a decline, as measured by key international measures such as the OECD's Programme for International Student Assessment (PISA).

Whilst broadly maintaining the general educational system used in England, the Welsh Government embarked on a 10-year revolutionary plan including the introduction of the Welsh Baccalaureate, an overarching qualification with a purely practical-based assessment incorporating transferable skills useful for higher education and employment, as well as explicitly using education as a lever to tackle socio-economic deprivation. Much of this plan was widely lauded by key stakeholders, being learner-focused and practitioner-led, placing an emphasis on skills development and ensuring that it is appropriate for the specific needs of Wales. However, since its implementation, it has been criticised for various reasons and by various stakeholders, in many cases due to the inconsistent approach to its implementation in schools. The Welsh Government's Minister for Education and Skills appointed in June 2010, in looking for the reasons behind Wales' failing education system, found cause to commission no fewer than 24 reviews before his resignation in February 2013—almost one per month, with a range of issues related to the teaching of information communications technology (ICT).

3.5 Ireland

From its outset, the academic study of computing in Ireland was strongly linked with the Irish software industry and the government's involvement in its growth [118]. Despite a population of less than 5 million, Ireland is home to the EMEA headquarters of many multinational tech firms, and 16 of the 20 top global technology companies have strategic operations in Ireland including Apple, Facebook, Google Microsoft and Twitter. Dell/EMC, Ericsson, HPE, IBM, Intel, and Oracle have all been present in Ireland since before 1990 and still maintain a significant presence there [14]. By 1988 Ireland was the second largest exporter of software in the world and the value of software exports exceeded that of agricultural exports [55]. Since then Ireland has remained the first or second largest exporter of software to present day.

A small population combined with a tightly integrated educational landscape (state-run second-level examinations, a centralised third-level admissions system, and the fact that all third-level computing department heads meet regularly—see Sect. 3.5.3) and a globally competitive technology industry creates a fertile environment for computing education and research. The presence of companies like Intel have directly influenced the computer science curricula of Ireland's third-level institutions [142]. Companies such as Ericsson have also had similar influence [14]. When asked what influenced their choice of programming language of instruction for introductory programming in a 2019 survey of introductory programming instructors representing 90% of all publicly-funded and 80% of privately funded institutions, 81% reported "relevant to industry" as the top reason out of 15 choices [14]. Ireland has also had a unique impact on global computing education. For example, CoderDojo was founded in Ireland in 2011 and is headquartered in Dublin [14].

CER activity in Ireland has seen unprecedented growth in the last 5 years. Buoyed by an exceptionally strong tech sector and spurred on by the launch of a national computing curriculum at upper second-level in 2018. These years have seen the birth of at least three new research groups, a sharp increase in publications, and hosting the ACM ITiCSE and UKICER conferences. In 2019 SIGCSEire, the Ireland ACM SIGCSE Chapter[28] was established and is now the second-largest SIGCSE chapter with 219 members spanning primary, secondary and higher education, students, industry and government representatives, as well as grass-roots educators such as CoderDojo mentors. As of mid-2022, Ireland has 137 publications at SIGCSE conferences going back to 1986 with every university represented. 72% of these have been published since 2017. Those with 10 or more contributions in the last 5 years include University College Dublin (67) TU Dublin (19), Maynooth University (15), Trinity College Dublin (14), Dublin City University (11) and NUI

[28] SIGCSEire.acm.org.

Galway (10). A detailed scientometric analysis of research publications from the UK and Ireland follows in Sect. 4.

3.5.1 Primary Computing Education in Ireland

There is no formal primary school computing curriculum, however research has investigated the inclusion of computing at primary level[29] as part of the national primary curriculum review.[30] In July 2016, the National Council for Curriculum and Assessment (NCCA) was directed to investigate approaches towards integrating "coding" and "computational thinking" into the primary curriculum.

In 2016 a review of primary-level efforts in 22 jurisdictions was conducted.[31] This report laid the foundations for a deeper investigation in 2018 when efforts in six locales (England, New Zealand, Finland, the US—Washington state with CSTA, Northern Ireland and Scotland) were investigated in detail.[32] This work reported commonality in terms of what is taught, insights on the need for cross-curricular implementations, and that continuing professional development of teachers is a priority in all six countries in the study. This research was preceded by a report from Millwood et al. [161] reviewing the literature on computational thinking. It concluded that computational thinking was an appropriate focus in primary education and should be implemented as a cross-curricular component of the wider curriculum. The authors also provided the caveat that "Unplugged approaches are useful, but must be clearly linked with progression to plugged activities".

Most often curricula are developed before they are implemented. However, the NCCA have investigated possible elements of a programming curriculum in parallel to the research previously mentioned. Phase 1 started in 2017 and involved working with schools.[33] Schools were selected based on the teachers having prior experience. The goals were to capture the current state and capabilities of informal computing at primary level, and to plan and share examples for phase 2. A range of school types and location were included including disadvantaged and rural schools. Phase two began in fall 2018,[34] with novice teachers with little to no prior coding experience. This was to inform future possible curricular developments and to gain understanding of the potential benefits of teaching coding, computational thinking, and physical computing through project-based pedagogical approaches. This was in

[29] ncca.ie/en/primary/primary-developments/coding-in-primary-schools/research.

[30] ncca.ie/en/resources/primary-coding_final-report-on-the-coding-in-primary-schools-initiative.

[31] ncca.ie/en/resources/primary-coding_desktop-audit-of-coding-in-the-primary-curriculum-of-22-jurisdictions.

[32] ncca.ie/en/resources/primary-coding_investigation-of-curriculum-policy-on-coding-in-six-jurisdictions.

[33] ncca.ie/en/primary/primary-developments/coding-in-primary-schools/work-with-schools-phase-1.

[34] ncca.ie/en/primary/primary-developments/coding-in-primary-schools/work-with-schools-phase-2.

essence a trial run for coding as the majority of teachers, if rolled out nationally, will not have taught coding before.

The capstone to the NCCA's research and working with schools phase one and two, prior to the national curriculum review, was the final report on the Coding in Primary Schools Initiative.[35] This brought together the foundational research, the phase 1 and 2 trials, and an additional research investigation involving collecting data from teachers, management, parents and students. The report concluded with the identification of three aspects of digital competence—creating with technology, understanding technology, and using technology—as fundamental to the inclusion of coding and computational thinking into the curriculum.

Following this, and with ongoing discussions and review, the NCCA have three current strands of commissioned research: creating with technology, understanding technology, and using technology. These are forming core components for the consideration of "digital technology" (the name suggested in the conclusion of the final report) in the current national primary curriculum review. The possible outcomes of this body of work are that digital technology: (1) will be a standalone subject in the new primary national curriculum, (2) will be integrated as a cross-curricular component in the new primary national curriculum, or (3) will not be considered in the new national primary curriculum.

Research

Several university groups work directly with primary schools and teachers. As all of these also work with second-level schools and teachers, they are included in Sect. 3.5.2 below.

Research themes at primary level have included: curriculum [207]; capacity, access & participation [132]; computational thinking primary school resources [141]; computing education policy [58, 162]; informal learning [3, 4]; and parental involvement in primary school computing education [36, 38, 39].

3.5.2 Second-Level Computing Education in Ireland

Ireland's first association for computing in primary and secondary education—with many third level members—was CESI (Computers in Education Society of Ireland).[36] CESI was established in 1973 and is the official (department of education associated) professional network for K-12 computing teachers.

35 ncca.ie/en/resources/primary-coding_final-report-on-the-coding-in-primary-schools-initiative/.

36 www.cesi.ie.

The Early Years

The early stages of computing education in Ireland were documented by McCarr in 2009 [151]. From 1975 CESI introduced early research in teacher professional development [151] and computing experiments in schools [167]. While there was a growth spurt in initiatives and activities such as teacher diploma courses in computing or a department of education white paper (all discussed in the McCarr report), a very noteworthy series of events occurred, which formed the first steps towards formal computing education at K-12 in Ireland. Perhaps most significant early success was in 1981 which saw the inclusion of an optional computing component in the upper second level mathematics subject. While this was a positive first step, there were several limitations including the computing component being optional, not formally examined by the State Examinations Commission (SEC), and a lack of consistent learning outcomes. Following this, the department of education developed a lower second level subject in 1984. However just like the computing component in mathematics at higher level, it was not formally assessed. Over time both of these initiatives were discontinued [151].

Similar to many other jurisdictions, the 1990s saw a focus on more generic ICT related skills. In Ireland, computing took a back seat to ICT during this timeframe for a multitude of reasons which are described in the McCarr report [151]. In 2000 the department of education published the IT2000 report[37] followed by the Blueprint for ICT in Education report [121]. These reports reflect the pressures and mindsets at the time in terms of the need for ICT skills. McCarr concluded that the rationale for a focus on ICT was based on economic factors as well as findings from the OECD, which showed that Ireland at the time was performing below average. The last serious move in the ICT direction was a 2007 NCCA report "ICT Framework—A structured approach to ICT in Curriculum and Assessment: Revised Framework".[38]

Recent Years

The 2010s saw a significant shift again, this time migrating towards the inclusion of computing curricula at lower and upper second level. The initial offering from the NCCA came in the form of a Junior Cycle Short Course in Coding, introduced in 2016.[39] A Junior Cycle short course is a 100-h course that can be delivered at varying stages across the 3 years of the Junior Cycle (approximate ages 12–15). They are classroom-based and assessed, with an emphasis on active learning. The short courses were not intended to replace existing subjects, but to allow schools to broaden the range of learning experiences for students, and to access areas of

[37] www.gov.ie/en/publication/eae94c-schools-it2000.

[38] ncca.ie/en/resources/ict_framework_a_structured_approach_to_ict_in_curriculum_and_assessment_-_revised_framework.

[39] www.curriculumonline.ie/getmedia/cc254b82-1114-496e-bc4a-11f5b14a557f/NCCA-JC-Short-Course-Coding.pdf.

learning not covered by the combination of curricular subjects available in the school. LERO (the Science Foundation Ireland Research Centre for Software[40]) was commissioned to write the short course. The process consisted of the specification (2014–2016), a pilot project (2016–2017) in collaboration with the JCT (Junior Cycle for Teachers support service) team and Intel.[41] This short course has three strands. The first is "computer science introduction". This has grounded links for computer science comprehension and the understanding of a notional machine. The second is titled "lets get connected". This strand develops communication and architecture comprehension with a related learning outcome to build a website using HMTL and CSS. The final strand is "coding at the next level".

The 2017 Digital Strategy for Schools report[42] was the first serious indication at what would become the computer science subject at upper second level—as a state assessed subject—putting it on equal footing to subjects like Biology, Geography or Physics. At this time, the then Minister for Education fast-tracked the development of the Leaving Certificate Computer Science (LCCS) subject.[43] After development of the curriculum (in Ireland called a specification), a staged roll-out began in 2018 with 40 schools.[44] A textbook for the curriculum was published in 2020 by Becker and Quille [25] and the subject is now being taught in over 150 of 722 schools. In 2020 a framework document was developed by the department of education to support the growth and uptake of the subject.[45]

The assessment of the LCCS consists of a 70% terminal examination (with discussion that it would be online - not yet realised) and a 30% mark for a practical project called an Applied Learning Task (ALT) based on one or more of the ALTs detailed in the course specification. The NCCA specifies that the subject be taught in Python and/or JavaScript. The main rationale for this was that a multitude of programming languages would be difficult to regulate or get assessors to grade (assessments are graded centrally by the SEC). Similar to the Junior Cycle Short Course, the Leaving Certificate course consists of three strands: "practices and principles", "core concepts" and "computer science in practice". The latter contains four applied learning tasks (ALTs), which compliment the first and second strands [192].

Research

Research themes at second-level have included: artificial intelligence & machine learning education [147]; computing education policy [37, 58]; capacity, access &

[40] lero.ie.

[41] lero.ie/epe/schools.

[42] assets.gov.ie/24382/7b035ddc424946fd87858275e1f9c50e.pdf.

[43] ncca.ie/en/senior-cycle/curriculum-developments/computer-science.

[44] www.gov.ie/en/press-release/1238e6-minister-bruton-announces-leaving-certificate-computer-science-subje/.

[45] www.gov.ie/en/publication/5986e-leaving-certificate-computer-science-framework-2020.

participation [132, 191]; computational thinking [116, 131] for teachers [163, 175]; confidence [90, 156]; curriculum [207], K-12 outreach [105, 157, 171, 205]; developing a nationwide MOOC for second-level students [173]; initial teacher education & professional development [47, 48, 88, 97, 98, 153, 174]; principals' & guidance counsellors' attitudes towards computer science in schools [152]; self-esteem, [223]; teacher & learner agency [197]; and teacher programming self-efficacy [89, 155]. It is unsurprising given that the Irish second-level Computer Science curricula was implemented in 2018, that there is a large body of research in K-12 curricula from Irish authors [57, 91–93, 192, 215].

3.5.3 Higher Education in Ireland

Enter Industry and the Birth of Computing Courses

IBM opened an office in Ireland in 1956 and the first academic computer—an IBM 1620—was installed at University College Dublin in March 1962 and UCD's computing strategy was initiated and led by its science faculty. This was quickly followed by the installation of another IBM 1620 in June 1962 at Trinity College Dublin in the engineering school [118]. In 1964 University College Cork installed an IBM 1620 model 2 in its electrical engineering building, and in 1967 University College Galway installed an IBM 1800 data acquisition and control system.[46]

Professor John Byrne, the founder and long-time head of Trinity's Department of Computer Science, had such an impact on Irish computing that he is known by many as the "Father of Computing in Ireland" [118]. He identified that a major limiting factor for the emerging technology sector globally was the lack of an appropriately skilled workforce. He was responsible for developing educational programmes and creating a foundation of skilled professionals that contributed to attracting computing businesses to Ireland [71, 118].

In 1963 an M.Sc course in Computer Applications began at Trinity and in 1969 a Computer Science Department was established there.[47] In 1970 UCD began a BSc in Computer Science [5]. It is unclear when their Computer Science Department was formally established, but it was in place by 1972 [196]. UCD graduated its first Computer Science BSc cohort in 1972, the same year the first Computer Science PhD graduated (supervised by the Mathematics department) [221].

Organisation: Industry, Government and Education

In 1967 the Irish Computer Society (ICS) was founded as the national body for Information and Communication Technology (ICT) professionals in Ireland. Since its foundation the ICS has promoted the development of professional ICT

[46] techarchives.irish/irelands-first-computers-1956-69.

[47] www.scss.tcd.ie/SCSSTreasuresCatalog/literature/TCD-SCSS-DeptHistoryFor50thBirthday-v0.30-27-A5.pdf.

knowledge and skills in Ireland. The ICS is a member of the Council of European Professional Informatics Societies (CEPIS) which maintains formal and informal links with the European Union and is recognised as a non-governmental organisation with consultative status by the Council of Europe.[48] In 1976 an Advisory Group for Computer Services was established by the Higher Education Authority. In addition to the Authority itself, representatives from higher education, institutions, government departments, and private sector companies would serve as members of the group [220].

In 1981 The Irish Science and Technology Agency (EOLAS)—a state-sponsored body focused on the IT area set up in 1977—produced a report on the Irish computing industry entitled Microelectronics: The Implications for Ireland. Included in its recommended policies for the sustainability of the IT industry was funding at tertiary level of computer-related education and the extension of information technology appreciation into all secondary schools [168]. In 1998 proposals were put to government covering actions including increased educational capacity at third level [111]. In 1991 The National Software Directorate (NSD) was set up to align industry with education, creating niches in the software market and value from research in the area of software technology [113] with a 1992 budget of 1.4 m [111]. Amongst its aims were helping coordinate educational activities, and promoting software as a career, particularly to second level students [55].

Interestingly, in 1998 Condon reported that there was a large gender disparity in Computer Science with students identifying as women significantly underrepresented and that one of the goals of the NSD was to make computing just as attractive for women as men [55]. Over 30 years later women are still very underrepresented in Irish computing. A 2017 survey of several hundred Irish introductory programming students found that only 24% of students identified as female, and noted that the Higher Education Authority reported only 15% of students in computing degrees identified as female [204]. Another 2017 study of over 600 students at ten Irish (and one Danish) institutions found that students identifying as female reported significantly lower programming self-efficacy [190]. A 2019 Higher Education Authority survey reported that only 19% of undergraduate and 24% of postgraduate Information and Communication Technologies (Computer Science is not analysed separately) students identify as female [86].

As director of the NSD, Condon identified that matching educational activities and industry needs in an area which had developed as rapidly as software was difficult. As a result, with the help of Enterprise Ireland, in 1992[49] a forum involving the heads of all third-level departments of computing, industry representatives, and the NSD itself was established. In 1998 this forum met about four times a year and had already emerged as a useful means for identifying common issues and concerns, and in providing a valuable input into policy formation [55]. This

[48] www.ics.ie/news/view/114.

[49] E-mail correspondence with Ted Parslow, Chairperson of the Third Level Computing Forum (2007-present).

forum still exists today as the Third Level Computing Forum,[50] and still meets four times per year, now with the Department of Education and Skills, the National Council for Curriculum and Assessment, and Enterprise Ireland all having regular representation. A key to the success of the Forum has been the participation of industry, government departments and semi-state and professional bodies in addition to all Irish higher education institutions and second level and guidance counsellor representation [179].

Recent Years

In recent years, increased focus has been placed on apprenticeships, upskilling, and teacher training (specifically for the second-level Leaving Certificate Computer Science curriculum). Currently there are dozens of university provided programmes at the Diploma and MSc levels available to those who wish to change careers or improve progression potential. Several of these are specifically designed for in-service teachers who would like to teach computer science at school level. There are also several Bachelor's degree programmes aimed at pre-service computer science teachers including the Bachelor of Arts Education (Computer Science and Mathematical Studies) at NUI Galway,[51] the Bachelor of Science (Education) in Mathematics and Computer Science at the University of Limerick,[52] and the BSc in Computer Science, Mathematics & Education at University College Dublin.[53] There are also postgraduate qualifications for in-service teachers who want to teach Computer Science such as the Masters in Computer Science for Teachers at the Technological University of the Shannon: Midlands Midwest[54] and the Masters in Computer Science Education Research at Atlantic Technological University.[55]

A major focus in computing education in Ireland in recent years has been on diversity, equality and inclusion. Four computing departments have received Athena Swan Bronze departmental awards: IT Carlow, Trinity College Dublin, University College Dublin, and the University of Limerick. In 2017 the Irish Network for Gender Equality In Computing: INGENIC was created to "to unite, coordinate, and boost efforts in addressing gender equality in computing across all third-level institutions in Ireland".[56] The network has representatives from the computing departments of every higher education institution in Ireland.

[50] thirdlevelcomputingforum.ie.

[51] www.nuigalway.ie/courses/undergraduate-courses/education-computer-science-mathematical.html.

[52] www.ul.ie/courses/bachelor-science-education-mathematics-and-computer-science.

[53] www.myucd.ie/courses/science/computer-science-mathematics-education.

[54] lit.ie/en-ie/courses/master-of-science-in-computer-science-for-teachers.

[55] lyit.inventise.ie/CourseDetails/D303/LY_KEDRS_M/ComputerScienceEducationResearch.

[56] ingenic.ie.

Working With Schools

Several universities lead efforts to work with schools in Ireland. The PACT (Programming + Algorithms $\approx$ Computational Thinking) group[57] based in Maynooth University develops resources and supports to allow teachers to teach topics in computer science at both primary and secondary school. PACT also coordinates school visits and workshops. Since 2012 PACT has engaged over 30,000 teachers and students with funding from Maynooth University Department of Computer Science, the Google CS4HS programme, and Science Foundation Ireland (SFI). CS_{INC} (Computer Science Inclusive)[58] based in TU Dublin organise student camps and workshops, teacher professional development as well as research in K-12 computing education. CS_{INC} has engaged tens of thousands of students and thousands of teachers in recent years. They also run CS_{LINC}, an online student learning environment consisting of several modules built upon international best practices which are tailored to Irish second-level students. CS_{LINC} has engaged over 10,000 students in the last 2 years. Bridge 21,[59] based at Trinity College Dublin, organises teacher professional development as well as working directly with schools and students.

Funding

There is no specialised source of funding for CER in Ireland. Funding can be sought from several disparate sources, however this typically requires that the direction of the research must be shaped to align with the aims of the funding body or particular call. Sources include The National Forum for the Enhancement of Teaching and Learning in Higher Education,[60] and Science Foundation Ireland (e.g. "Discover" calls). Additionally, regional and international (e.g. European Union) funding is available for specialised calls, in addition to globally-scoped special funds (e.g. SIGCSE Special Projects Grants).

Research

There are several large computing education research groups in Ireland including NUI Galway, the Computer Science Education Research (CSER) Group at Maynooth University,[61] CS_{INC}[62] at Technological University Dublin, and the University College Dublin Computing Education Research Group (CERG@UCD).[63]

57 pact.cs.nuim.ie.

58 csinc.ie.

59 b21.scss.tcd.ie.

60 www.teachingandlearning.ie.

61 www.cs.nuim.ie/research/cser.

62 csinc.ie.

63 cerg.ucd.ie.

LERO, the Science Foundation Ireland (SFI) Research Centre for Software[64] also conducts computing education research. Combined these groups have produced approximately a dozen PhDs and have over two dozen current PhD students focused on computing education.

Research themes in higher education have included: achievement goals / mindset [188, 228]; AI-generated code [96]; artificial intelligence in education [13]; assessment [35, 170, 194]; classroom terminology [12, 15, 19]; computing education theory [65, 206]; diversity, equality and inclusion [164, 172, 190]; frame-based editing [41, 80]; group projects [27]; identifying at-risk students [22]; introductory programming / CS1 [18, 24, 115, 144, 158] in Ireland [14]; metacognition [75, 143, 183–185]; non-native English speakers [1]; notional machines [78, 79]; novice programmer behaviour [127, 128]; predicting programming success [10, 28, 50, 51, 186, 187, 189, 193]; prior programming experience [204]; program comprehension [45]; programming anxiety [56, 61]; programming error messages [16, 17, 20, 21, 23, 52, 74, 76, 126]; retention [59]; sense of belonging [165, 166]; soft-skills and creativity [107, 108]; student anxiety [170]; and teaching programming to adults [60].

4 Scientometrics of CER in the UK and Ireland

Having surveyed the factors that have influenced the development of CER in the UK and Ireland, we now review the outputs in a scientometric analysis. The analysis is based on a data-set that was retrieved from SCOPUS through a search based on keywords and publication venue. The retrieved data were manually checked for relevance, cleaned, checked and verified as described in detail in an earlier chapter [145]. In addition to the venues already identified, we add Computing Education Practice (CEP) and the UK and Ireland Computing Education Research (UKICER) conferences. Not all relevant papers are captured through this search. In particular the International Journal of Computer Science Education in Schools (IJCES) https://www.ijcses.org/ is not indexed in SCOPUS, although it does appear in Google Scholar, ERIC and Crossref. For this chapter, only articles with an author with a UK or Irish affiliation at the time of article publication were included regardless of the author order. The total number of articles was 1301. The author, institutions, and country networks were constructed using the fractional counting methods. The structural topic model analysis was based on the topics created using the methods in another chapter [7].

[64] lero.ie.

4.1 Data Cleaning

Detailed manual cleaning of the identified set of papers was carried out for the base data-set, and then further work was done to identify current research institutions (mainly Higher Education Institutions) in the UK and Ireland corresponding to the institutional affiliations listed in the original papers. Different types of changes were made to institution titles

1. Grouping of different names of the same institution e.g. UNIVERSITY OF KENT, UNIVERSITY OF KENT AT CANTERBURY, UNIV OF KENT AT CANTERBURY, UNIV. OF KENT, UNIVERSITY OF KENT CANTERBURY
2. Renaming of institutions to their current title, for example SHEFFIELD POLYTECHNIC became SHEFFIELD HALLAM UNIVERSITY as part of the 1992 founding of "new universities" in the UK from former polytechnics and central institutions
3. Renaming following merger of institutions e.g. PAISLEY COLLEGE OF TECHNOLOGY became part of the UNIVERSITY OF THE WEST OF SCOTLAND
4. De-merging of institutions that were listed with the same title e.g. ABERYSTWYTH from UNIVERSITY OF WALES, MAYNOOTH from NATIONAL UNIVERSITY OF IRELAND
5. Shortening to familiar abbreviations e.g. QUEEN'S UNIVERSITY BELFAST to QUB
6. Identification of institution titles where sub-institutional titles had been extracted e.g. SCHOOL OF COMPUTING

This was not a straightforward process as no one author had enough knowledge of the different institutions. Most of the identification was done through automatically extracted institutional affiliations, but some required going back to the original papers e.g. for de-mergers.

4.2 Number of Publications and Citations

The most basic counts that can be made of published research are the number of publications and the number of citations. Figure 1 shows the historical trend of the total number of CER papers published by authors affiliated with institutions from the UK and Ireland. In many cases there is collaboration between institutions and countries, so these are apportioned according to the number of authors. Whilst it would be possible to further break down the paper count to differentiate between Wales, Scotland, Northern Ireland and England, presenting the sometimes small volumes and multiple combinations of collaboration makes this too difficult to present in this way. Figure 2 shows only the trend in papers including authors at institutions from the UK and Ireland.

There is a noticeable surge in publications in the mid-1990s, shortly after the conversion of former UK polytechnics to universities, and in Ireland the foundation of Institutes of Technology (IoT), both in 1992. It is possible that staff at these institutions, which had a mainly teaching remit, looked to generate research outputs based on their teaching. There is no comparable increase in publications internationally in the mid-1990s so the proportional contribution of the UK and Ireland to all CER publications increased dramatically during this period.

This late-90s surge then drops away, before another surge in 2005, possibly in response to the desire to address curriculum and pedagogy in the light of falling numbers of computing students in universities. Finally there is an increase from 2015 onward, possibly driven by curriculum reform in schools [43] and the Shadbolt report on employability [201]. Some of the peaks in proportional paper output coincide with ITiCSE conferences being held in Ireland and the UK (1998, 2004, 2019) but other ITiCSE conferences held here (2001, 2013) do not seem to have the same effect, so it seems likely that these other influences have an important effect. The current peak in outputs and proportion of all outputs is reflected in, and partly driven by, the establishment of the ACM SIGCSE chapters in Ireland and the UK, and outputs from Computing Education Practice (CEP) and UK and Ireland

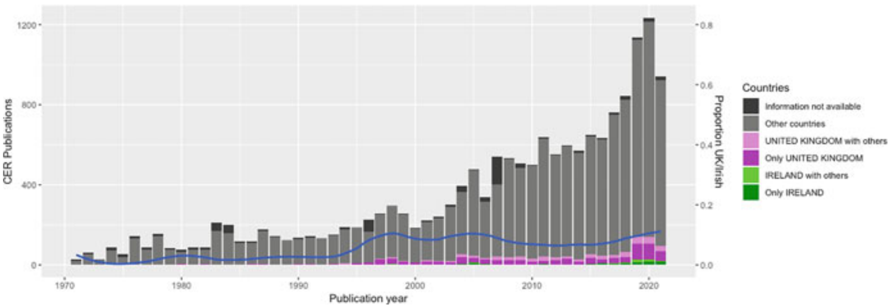

Fig. 1 Total articles by year. Blue lines show proportion (smoothed) of all CER publications that included authors from the UK and Ireland

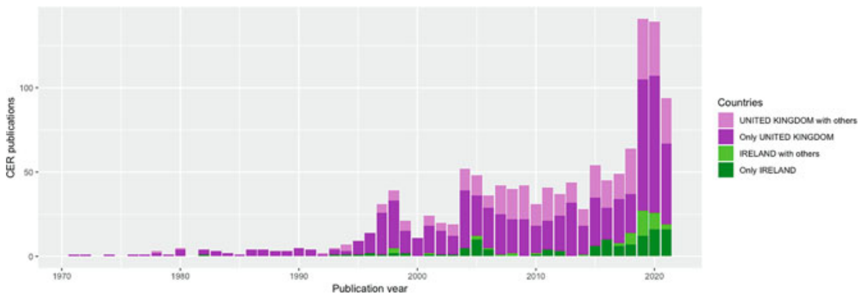

Fig. 2 Total articles by year from UK and Ireland

Computing Education Research (UKICER) conferences. Both of these conferences started publishing with ACM ICPS—and hence are included in this scientometric analysis—since 2019.

4.3 Most Frequently Cited Papers

Table 1 lists the papers that include authors from the UK and Ireland that have had the most citations per year (CPY) since publication. These are dominated by papers about teaching of programming, but with important contributions around school curriculum, particularly following on from the development of national curricula in schools from 2014.

4.4 Collaboration Networks

It is relatively straightforward to identify the names of collaborating authors, as they are listed directly in the search results. These data can then be used to build a network, where the edges represent paper collaborations, apportioned according to the number of authors. Representing this network graphically, where frequently collaborating authors are placed near to each other, is shown in Fig. 3. The size of the nodes corresponds with the amount of collaboration—which is not a very reliable measure because it is assumed that for any given paper all listed authors make the same contribution to it.

Following the cleaning of institutional affiliation data, a collaboration network can similarly be constructed for institutions, see Fig. 4. It is noticeable that a large proportion of the institutions listed are not in the UK or Ireland. This may be because the community is outward looking and keen to engage with educators and students in other contexts—or that researchers are often isolated and hence more likely to find collaborators at international conferences than within their own or neighbouring institutions. Table 2 shows how international conferences dominate the venues of CER publications from the UK and Ireland. Figure 5 shows the co-publication relationships between different countries explicitly. It is noticeable that authors from the UK are much more likely to collaborate with colleagues in the USA than colleagues in Ireland, and vice versa, although this could be explained simply by the number of researchers and outputs from the USA. In general it is surprising how little the level of collaboration depends on geographical proximity, or even a common language.

Table 1 Most-cited articles with total number of citations (C) ordered by citations per year (CPY) with CPY > 10. List of authors includes first author and any authors from the UK and Ireland

Title	Year	Authors	C	CPY
Failure rates in introductory programming revisited	2014	Watson & Li	283	35.4
Introductory programming: a systematic literature review	2018	Luxton-Reilly, Simon, Becker, et al.	125	31.3
A multi-national, multi-institutional study of assessment of programming skills of first-year CS students	2001	McCracken, Utting, et al.	453	21.6
Computing in the curriculum: challenges and strategies from a teacher's perspective	2017	Sentance & Csizmadia	107	21.4
A survey of literature on the teaching of introductory programming	2007	Pears, Devlin, Paterson, et al.	317	21.1
Restart: the resurgence of computer science in UK schools	2014	Brown, Sentance, Crick & Humphreys	142	17.8
37 Million compilations: investigating novice programming mistakes in large-scale student data	2015	Altadmri & Brown	119	17.0
Computer science in K-12 school curricula of the twenty-first century: why, what and when?	2017	Webb, et al.	81	16.2
Automatic test-based assessment of programming: a review	2005	Douce, Livingstone & Orwell	250	14.7
Educating the internet-of-things generation	2013	Kortuem, Bandara, Smith, Richards & Petre	117	13.0
The impact of covid-19 and "emergency remote teaching" on the UK computer science education community	2020	Crick, Knight, Watermeyer & Goodall	26	13.0
A systematic review of approaches for teaching introductory programming and their influence on success	2014	Vihavainen & Watson	103	12.9
The greenfoot programming environment	2010	Kölling	149	12.4
Compiler error messages considered unhelpful: the landscape of text-based programming error message research	2019	Becker, et al.	32	10.7
No tests required: comparing traditional and dynamic predictors of programming success	2014	Watson, Li & Godwin	84	10.5
Teaching introductory programming: a quantitative evaluation of different approaches	2014	Koulouri, Lauria & Macredie	84	10.5
A multi-national study of reading and tracing skills in novice programmers	2004	Lister, Fone, Thomas, et al.	185	10.3
Developing assessments to determine mastery of programming fundamentals	2018	Luxton-Reilly, Becker, McDermott, et al.	40	10.0
50 years of CS1 at SIGCSE: a review of the evolution of introductory programming education research	2019	Becker & Quille	30	10.0
Source-code similarity detection and detection tools used in academia: a systematic review	2019	Novak, Joy, et al.	30	10.0

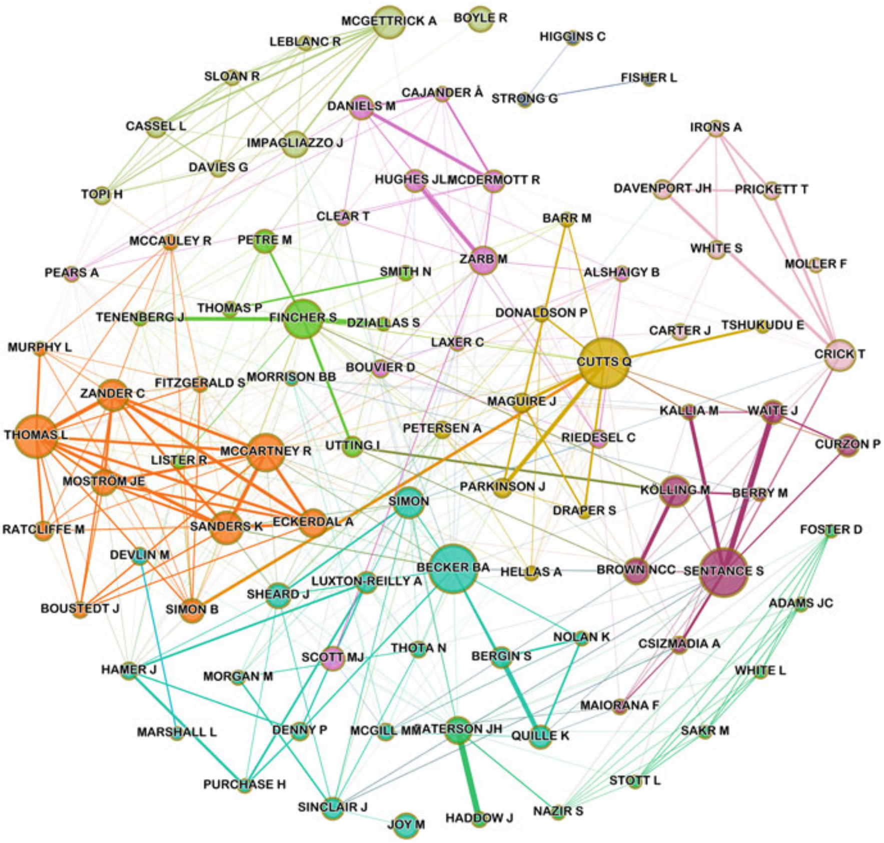

Fig. 3 Author collaboration for outputs including institutions in the UK and Ireland. Colours denote clusters of collaborating authors

4.5 Topic Modelling

Figure 6 shows how the subject content of published articles has changed over time. This analysis was performed by carrying out topic modelling on the titles and abstracts of papers, with apportionment of papers between topics where multiple topics were identified (see [7]). There are some interesting trends to note in terms of the total number of articles published, and we break these down into five main patterns: steady; emerging; receding; fluctuating; and missing.

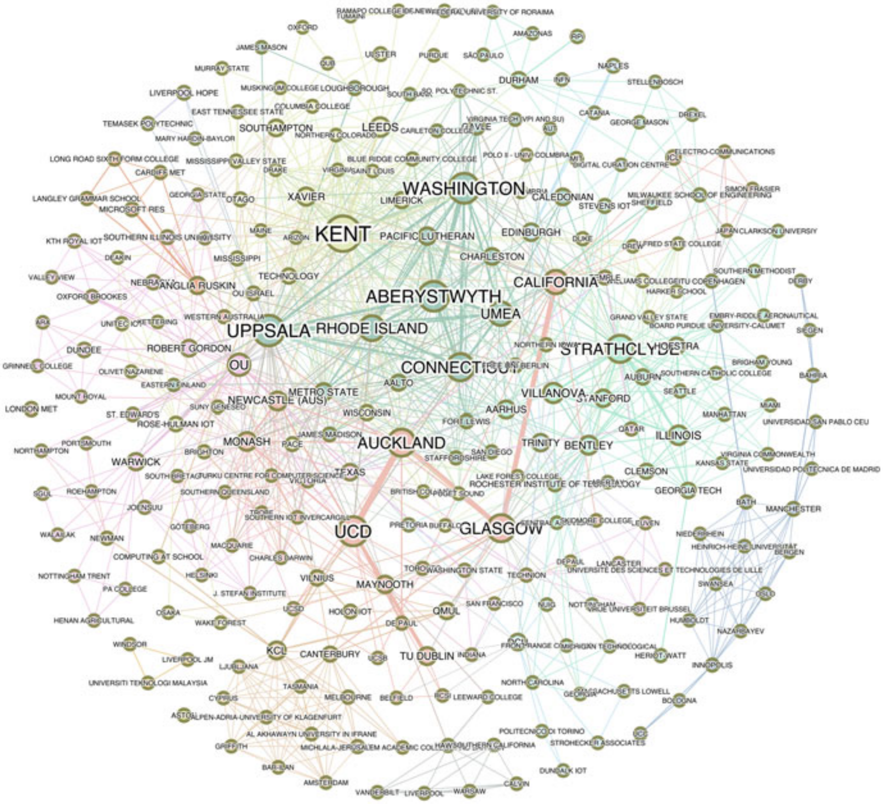

Fig. 4 Institution collaboration for outputs including institutions in the UK and Ireland. Colours denote clusters of collaborating institutions

4.5.1 Steady

Some topics have sustained a fairly constant rate of publication, particularly when considering the overall increase in the number of papers. Programming, Assessment and Pedagogy fall into this category, although at different levels of activity. Programming has always had a high number of papers, and the top three papers in terms of citations per year are also in this area (see Table 1).

4.5.2 Emerging

Coverage of these topics has increased substantially over the period: Computational Theory; Computational Thinking; Data Mining; Educational Psychology; Gender and Diversity; Introductory courses; Projects; STEM. In some cases this is relatively unsurprising, for example Gender and Diversity have rightly had increasing public

Table 2 Venues that have published 10 or more papers by authors from the UK and Ireland

Venue	Publications
Innovation and Technology in Computer Science, ITiCSE	437
ACM Technical Symposium on Computer Science Education, SIGCSE	140
ACM SIGCSE Bulletin	92
International Conference on Educational Research, ICER	70
Conference on Computing Education Practice, CEP	59
Workshop in Primary and Secondary Computing Education, WiPSCE	44
Koli Calling International Conference on Computing Education Research	41
Computer Science Education	36
Frontiers in Education Conference, FIE	33
UK and Ireland Computing Education Research Conference, UKICER	30
ACM Transactions on Computing Education, TOCE	29
International Conference on Informatics in Schools, ISSEP	13
ACM Journal on Educational Resources in Computing	10

focus in general, and specifically within HE through the Athena Swan scheme [216]. Computational Thinking is (arguably [208]) a new subject area and research into Data Mining education reflects the growing amount of data that is collected and used as part of our every day lives. Perhaps more surprising is the growth in the numbers of papers about Projects, given that project work has long been an important and sometimes difficult area of computing education.

4.5.3 Receding

After early interest in Design and OOP there have been relatively few recent articles on these topics, following peaks in 2004 and 2008 respectively. Education Technology within computing education research has also experienced a reduction in the total numbers of papers, and a marked diminution in the proportion of all CER articles written in the UK and Ireland.

4.5.4 Fluctuating

All of the topics show fluctuation, but there are some particularly noticeable variations. Software Engineering (SE) has fallen and then risen again, possibly reflecting a move away from traditional SE techniques and an emergence of interest in agile methodologies. Programming Languages have followed a similar pattern, perhaps following the trend for adoption of Java in the early part of the century (relating also to a growth in OOP), a period of stability and then a move towards python. Curriculum has also had a surge of interest coinciding with the introduction of national curricula in schools in the 2010s. It might be assumed that artificial

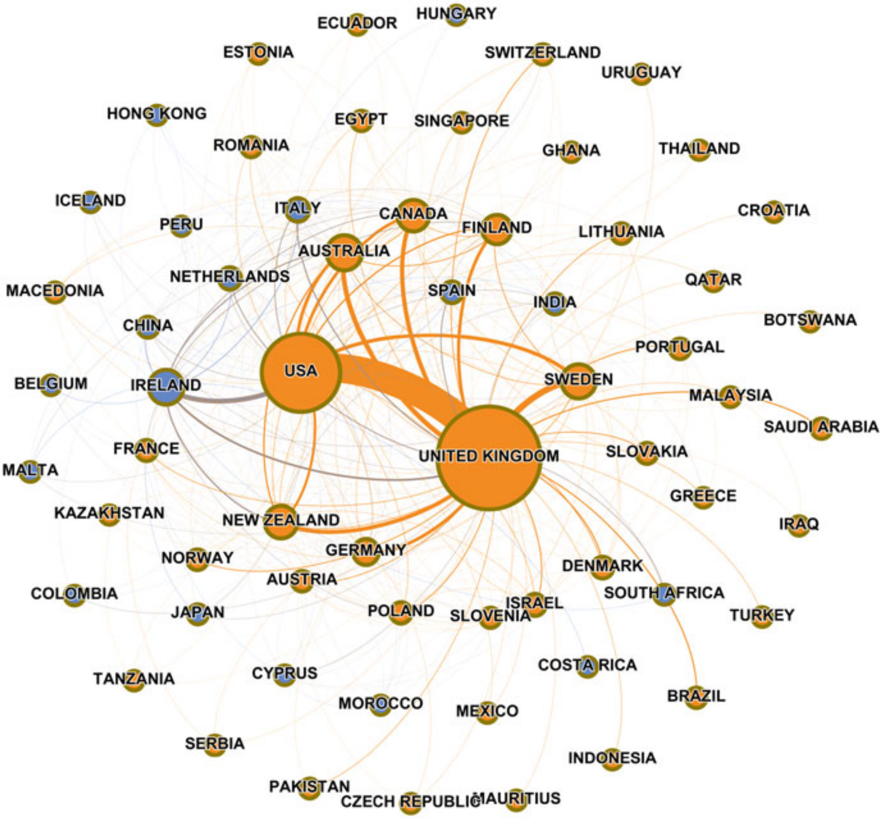

Fig. 5 International collaboration for outputs including institutions in the UK and Ireland. Colours denote clusters of collaborating countries

intelligence and machine learning would be relatively recent ventures, in parallel with Data Mining, but these have really experienced only a slight recent renaissance, with the peak of interest (proportionally at least) in 2004/5.

4.5.5 Missing

Some topics—Databases and Networks—are surprising in their absence from the list, given how much curriculum time is given to them at school and university. Alongside small numbers for Computer Architecture and Operating Systems, it seems that computer systems topics in general are under-represented. We might similarly have expected to see more on web and internet systems/programming given how central they are to industrial practice, as well as computing syllabuses. Security, mobile, and cloud computing are also missing from this list of the most common topics, possibly because they are relatively new and systems-focused.

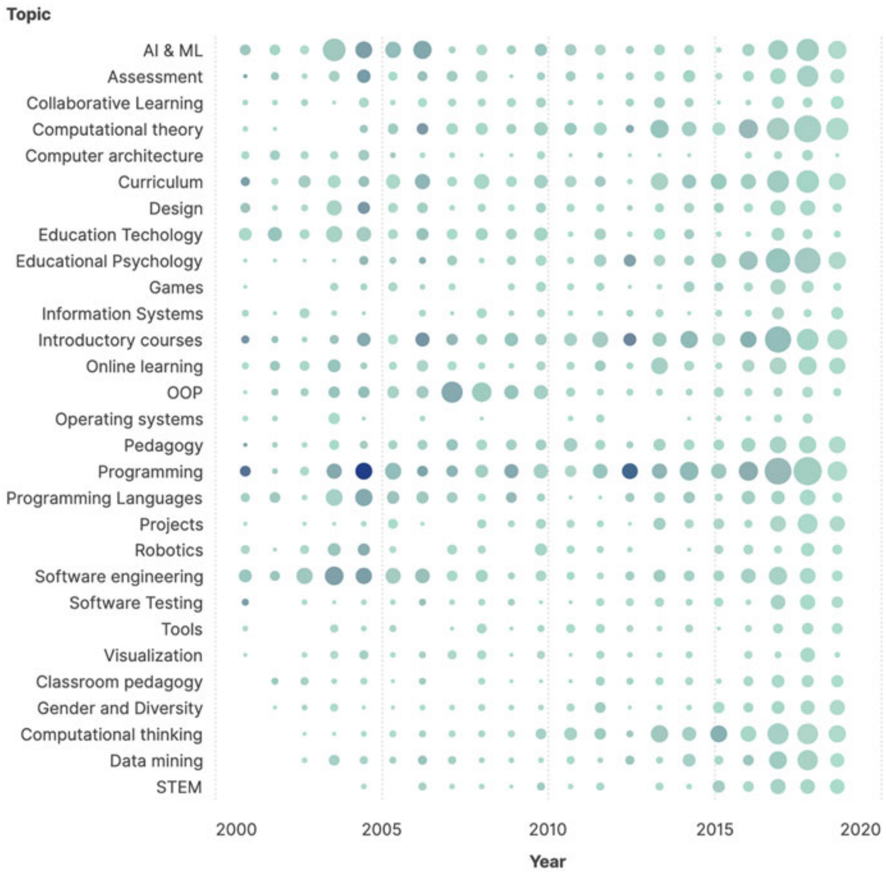

Fig. 6 Topics by year. The size of the circle represents the number of papers published, the darkness represents the number of citations received

5 Discussion

CER in the UK and Ireland has a long history for such a young subject. The British Isles have made strong contributions to the global CER community, and maintain robust international collaborations. At the time of writing that contribution is at an all-time peak of activity based on the proportion of all CER papers published internationally. Our CER community has contributed strongly to the establishment of national curricula, as the UK and Ireland have been in the vanguard in terms of pre-university computing.

However, much of the CER in the British Isles has come from researchers whose interest is strong enough, and university situations and commitments flexible enough, to allow for the dedication of time and resources to effect meaningful work.

Government funding, when it has come, has usually targeted the delivery of training, such as the National Centre for Computing Education or the Institute of Coding. Some basic research has fallen out of this funding driven by the interest of the people working on it.

Nonetheless, CER is not well funded in the UK and Ireland, with no national government grant-awarding bodies having the area within their specified remit. To some extent this is due to issues of intersectionality: should it sit within education research funding or computing research funding? Should the quality of the research be assessed by an education panel or a computing panel? And should research into teaching children about computing be done in schools or universities? Much of this can be put down to the relative youth of the subject within university settings, where funding for more traditional subjects dominate. However it is notable that other countries do have national funding that is accessible to computing education researchers e.g. the NSF in the USA.

Because most tenured academics are required to carry out teaching as well as research activities, CER outputs are often rooted in the authors' own teaching practice or interests, rather than in funded projects. To some extent this gives a welcome freedom because the direction of research is not usually dictated by national policy initiatives, and researchers can choose to follow their own path. Most teachers in schools, however, don't have the time or training to engage in research, so outputs are more often focused in Higher Education, where scholarship and research is a more central expectation.

This chapter has documented the CER conducted in the UK and Ireland, demonstrating that there is a vibrant CER community that has conducted significant research at primary, second-level and higher education. This research spans the entire range of CER including classroom practice and pedagogy, student well-being, tools, outreach, theory, diversity, curriculum design, policy, and global engagement to name a few.

Looking forward, recent growth in computing student numbers has lead to an increase in university staff, which may lead to further engagement in CER. It would be interesting to explore the scientometric data to see the extent to which new people are joining the CER community. Emerging topics identified from the analysis are AI and machine learning, educational psychology, computational theory and diversity, equity & inclusion. Like most of the rest of the world, we continue to struggle with introductory programming, assessment (particularly plagiarism) and effective and realistic pedagogical approaches. Whether these topics will still be the main focus in 10 years time depends on developments in the subject and its pedagogy, but mainly on the interests of staff engaged in teaching—unless a source of regular government funding is made available to steer the direction of the community.

Like the rest of the global CER community, much work is outstanding. In the UK and Ireland, both of which have relatively well established second-level computing programmes, research into the transition from secondary school to higher education is needed. Additionally, how to teach computing to primary school children is an open question. Further, the current state of poor retention at university level, and poor uptake in secondary schools, combined with significant under-representation of many groups in student bodies, all demand more research. These topics will require more research into sense of belonging, the student experience, and tackling persistent problems with misconceptions of computing in the general population, particularly pre-university students and their parents. Finally, the UK and Ireland, along with all other countries, are now at the beginning of a new era—one defined by artificial intelligence finally, and rather suddenly, delivering real changes—and concerns—that affect the very nature of not only the academic discipline of computing but the way that it is taught and learned. One of the biggest challenges is that AI is now advancing faster than institutional, governmental, and social processes can adapt. This demands significant research presently.

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