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A university-based model for supporting computer science curriculum reform

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Abstract Computer science curriculum reform in the United Kingdom has been subject to substantial scrutiny—as it has in many other countries around the world—with England introducing a radical new computing curriculum from September 2014. However, in Wales—a devolved nation within the UK—political, geographical and socio-cultural issues have to date hindered any substantive educational policy or curriculum reform for computer science. In this paper, we present the activities of Technocamps, a national university-based schools outreach programme founded in 2003, and consider its wider impact on computer science education, schools, pupils and teachers in Wales. In contrast to successful interventions elsewhere in the UK in building and sustaining communities of practice, certain political and cultural challenges in Wales have largely prevented these successful models from being adopted. Through the consideration of the national case study presented in this paper, we demonstrate the necessity of the nation-wide school- and student-focused Technocamps model in building resilient and scalable practitioner-led support networks. Furthermore, with emerging curriculum reform in Wales, we frame the wider opportunity for computer science education and sustainably embedding cross-curricular digital competencies—along with changing the wider public perception and perceived value of computer science as an academic discipline—as a prospective replicable case study of a national engagement model for nations with similar aspirations of developing digitally confident and capable citizens. To this end, we conclude by drawing out the important lessons learnt for consideration when embarking on a programme of national curriculum reform and associated professional development.

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Introduction

There is significant international focus on recent and prospective computer science curriculum reforms—in the UK, as well as elsewhere. A number of audits and studies of national-level curricula models in different countries have been conducted over the past decade (CAS 2011; Hazzan et al. 2008; Snyder 2012; Sturman and Sizmur 2011; Hubwieser 2013; CECE 2017), with numerous nations and states engaged in efforts to revamp their compulsory-level computer science curricula (Hubwieser et al. 2015; Webb et al. 2017). Relevant examples include the USA, both nationally (ACM, Code.org, CSTA, Cyber Innovation Center, & National Math and Science Initiative 2016) and at the state level (Ericson et al. 2016; Guzdial et al. 2014); France (Baron et al. 2014); Italy (Bellettini et al. 2014); India (Raman et al. 2015); Israel (Armonia and Gal-Ezer 2014; Gal-Ezer and Stephenson 2014); New Zealand (Bell 2014; Bell et al. 2014); Russia (Khenner and Semakin 2014); Sweden (Rolandsson and Skogh 2014); and Hong Kong (Kong 2017). Each country has its own issues to address—educational as well as socio-economic—and barriers to overcome in implementing a high-quality, valued and sustainable computer science curriculum, along with ensuring that there is the confidence and capability in the teaching profession to deliver it effectively (Passey 2017).

Whilst this surge of activity has largely only arisen in the new millennium—no doubt due to the increasing demand for programming skills for the burgeoning "digital economy" (Tuomi et al. 2017; Murphy et al. 2017)—recommendations for academic computer science curricula have a long pedigree (Atchison et al. 1968). Despite reports of success from various jurisdictions—with clear economic levers underpinning the establishment of computer science as a worthwhile and high-value subject being a frequently named goal—addressing curriculum change to incorporate computer science represents a significant challenge in terms of scaling grassroots initiatives (Repenning 2018). This is particularly relevant for pedagogic research, assessment and teacher training (Vahrenhold 2012; Sentance and Waite 2018), from early years of education (Bird et al. 2014; Beauchamp 2016; Manches and Plowman 2017) through to higher education (Davenport et al. 2016), as well as in the wider context of developing effective pedagogies for the digital age (Beethan and Sharpe 2013).

It is within this wider educational and socio-economic policy context that we consider the case of computer science curriculum reform in the UK, specifically through the critical lens of a national case study in Wales compared against the more established computing curriculum in England that commenced from September 2014 (Department for Education 2013). By so doing, we expose the various issues which impact on the effectiveness of different initiatives aimed at effective adaption of curriculum reform. Through this Welsh national case study, we highlight the dominance of curriculum reform approaches in England influencing interventions across other parts of the UK, with potentially negative consequences for supporting practitioners pre-curriculum reform, as well as in geographically isolated areas.

To frame this national case study, we present *Technocamps,*[1] a national university-based schools outreach programme based at Swansea University, which was founded in 2003 to address the issue of computer science education given the specific challenges posed in Wales. The wider portfolio of activities carried out by the Technocamps project is described and discussed in detail in Crick and Moller (2015), framed by the key educational challenges that exist in Wales, along with a preliminary evaluation of the Technocamps interventions.

In this paper, we consider the wider impact of the Technocamps project and its potential replicability as a case study of a national engagement model for other similarly sized countries, and regions of a comparable geo-political composition to Wales, that are on a similar computer science curriculum reform journey. Furthermore, we demonstrate the necessity of the school- and student-focused Technocamps model in building resilient and scalable practitioner-led support networks. We evidence this through the consideration of the measurable effects of the Technocamps approach on schools, teachers and pupils, contextualised by emerging educational (and socio-economic) policy change, particularly with respect to reform of computer science and repositioning of cross-curricular digital competencies in compulsory education in Wales.

The structure of the paper is as follows. In "A brief history of computer science education in the UK" section, we describe the evolving state of computer science education in the UK, from a high-point in the 1980 s, through a slow decline, into the recent drive for curriculum reform. In "Wales: a case study" section, we direct our attention to the state of Welsh education which, we evidence via international comparators, has in some ways suffered a steady 20-year decline since devolution compared to the rest of the UK. In particular, we outline the social, cultural and infrastructural challenges which have been the driver for significant national curriculum reform, particularly for science and technology. "Technocamps: a university-based engagement model" section presents the key results represented in this paper; we briefly describe the Technocamps model and provide empirical evidence attesting to the effectiveness of this model compared to the model of school outreach employed extensively and effectively in England. Finally, in "Conclusions and lessons learnt" section, to aid potential transferability of the Technocamps approach for nations and regions with similar challenges to Wales, we make a number of recommendations through "lessons learnt".

A brief history of computer science education in the UK

In the 1980s, computer studies was a popular subject in schools across the UK. The availability of the popular BBC Micro—which was of little practical use unless you were able to programme it—saw a large proportion of school children learning the

[1] http://www.technocamps.com.

fundamentals of programming in a curriculum which included a variety of complementary topics such as hardware, software, Boolean logic and binary number representation.

By the 1990s, the emergence of pre-installed software—specifically office productivity software such as word processors and spreadsheet programmes—meant that computers were no longer predominantly machines that needed to be programmed in order to do anything useful or interesting. Less and less time was being spent in the computer studies classroom on thinking about and writing programmes, as basic digital literacies and IT user skills became regarded as the priority. However, as interest in viewing the computer as a creative tool waned in favour of using it for more mundane tasks, various problems were being created which were highlighted by two independent national enquiries in 1997 (Stevenson 1997; McKinsey & Company 1997). Both reports concluded that "*Information Technology*" in UK schools was in a primitive state and in need of attention and major investment. In line with the Stevenson Report (1997), computer studies evolved into a new subject whose name was coined in that same report: *Information and Communications Technology* (ICT). Over the decade starting in 1997, the UK Government invested over £3.5bn in ICT in schools through various funded interventions such as the *National Grid for Learning* and the *New Opportunities Fund* (Doughty 2006).

By the year 2000, ICT had permeated both primary and secondary school curricula. The emphasis was on developing the learner's IT skills and digital literacy in an attempt to address the increasing societal need for broader and transferable digital competencies, as well as supporting technology-enhanced learning (McNaughton et al. 2017). However, despite enormous government-funded ICT initiatives, various reports throughout the decade identified problems with implementing government policy on ICT educational reform (Opie and Fukuyo 2000; Ofsted 2004, 2013; Loveless 2005). The problems identified by these reports are summarised by Younie (2006) into five key areas, including management, teacher training and competence, and impact on pedagogy. The ICT curriculum in Wales (Welsh Government 2008)—whilst generally viewed to be more flexible and less prescriptive than the equivalent subject in England—exhibited many of the same issues (Estyn 2013, 2014). Highlighting the problems surrounding teacher competence, a full two-thirds of ICT teachers in the UK did not have a relevant qualification but moved into the role of ICT teacher simply by being sufficiently digitally literate (Royal Society 2012). The situation remains poor in Wales, where the raw number of ICT teachers is dropping at an alarming rate. Despite various initiatives and generous financial incentives on offer to computer science graduates to take up teacher training, Table 1 shows that the number of ICT (computing) teachers in Wales dropped by 15.9% over the past 5 years (N.B. the number of 0–10-year-olds in Wales, meanwhile, increased by 5.0% over this same period[2] from 375,690 to 394,370).

Whilst the percentage of ICT teachers with some form of ICT training has risen moderately from 33.0 to 39.9% over the same period, due to the drop in absolute

[2] https://gov.wales/statistics-and-research/population-0-19-year-olds.

Table 1 ICT teachers and their levels of ICT training

	2012	2013	2014	2015	2016	2017
ICT teachers	797	762	746	726	704	670
ICT trained	33.0%	35.9%	37.6%	38.4%	39.4%	39.9%

https://www.ewc.wales/site/index.php/en/policy-hub/archived-annual-statistics-digest

numbers this merely means that the number of such teachers has remained constant. There remains an expanding gulf between teacher supply and the urgent demand to satisfy the needs of education in the digital age.

This lack of teacher competence has a direct impact on school children: applications to study computer science at university slumped in the early part of the millennium—especially amongst females—and many of those who started a university computer science degree course found themselves dropping out during the first year, surprised at what computer science is and what studying it entails.

Two more recent high-profile national policy reports—one by Nesta (Livingstone and Hope 2011) and the other by the Royal Society (Royal Society 2012)—made the very same observations. Both reports noted that ICT suffers from a poor reputation amongst pupils, parents and industry, who consider it dull and unchallenging and hence a low-value discipline, especially compared to other "strategically important and vulnerable" Science, Technology, Engineering and Mathematics (STEM) subjects (HEFCE 2011). With ICT largely embedded across the primary school curriculum, secondary school pupils found ICT in secondary school neither stimulating nor engaging (Sentance et al. 2012). A review of vocational education for 14–19-year olds in the UK (Wolf 2011) further notes that the undemanding nature of ICT qualifications in secondary schools is readily exploited by schools: due to a disproportionately high national league table weighting associated with vocational qualifications, easily-achieved high results in ICT offer a welcome boost to a school's league table position. Furthermore, as ICT is typically presented by schools as their "computing" offering, students who might otherwise enjoy studying computer science are actively put off from what they are incorrectly but innocently led to believe is computer science (Crick and Sentance 2012; Brown et al. 2013), as well as wider challenges surrounding gender, diversity and socio-economic differences in ICT and computing (Kemp et al. 2018).

The development and implementation of a new computing curriculum in England from September 2014 (Department for Education 2013) provided a significant shift from ICT to computing, but provided little lead time to support existing teachers in their transition to this new curriculum. The grassroots organisation Computing At School (CAS)[3]—formed in 2008 to support teachers and address the perceived challenges of declining computing in UK schools—played a central role in this curriculum reform process in England (Brown et al. 2013, 2014). A central pillar of the CAS model in England is a "Network of Excellence" (Sentance et al. 2014), in

[3] https://www.computingatschool.org.uk.

which regional "Master Teachers" develop subject knowledge as well as pedagogical skills in a local, face-to-face, peer-to-peer delivery model. Whilst largely successful in densely populated urban areas, providing easy networking and the ability to form active communities of practice, a number of challenges to scaling and sustaining this approach have been identified (Sentance and Csizmadia 2017; Sentance and Waite 2018), including developing pedagogic content knowledge (Hidson 2018). A related model has also been developed in Scotland, with similar challenges identified (Cutts et al. 2017).

In November 2017, the Royal Society published a report (Royal Society 2017) which was a follow-up to its earlier report (Royal Society 2012) which had catalysed the curriculum reform process in England. This second report articulated many of the challenges discussed above in supporting "computing for all", highlighting the scale of funding and changes to policy and practice required to make this a reality. In particular, alongside curriculum and qualifications reform, it stressed the importance of teacher recruitment and in-service training, as well as evidence-informed practice, particularly the need for effective pedagogic approaches for teaching computing.

Wales: a case study

Having outlined the state of education in the UK as a whole, we now restrict our attention to Wales. As our aim is to identify the requirements for effective curriculum reform in a nation or region which enjoys the same characteristics and challenges as Wales, we start by describing these characteristics. We then outline the recent history of education and curriculum reform with particular emphasis on ICT and computing.

A devolved nation in the UK

The UK consists of four nations historically ruled by one parliament, with an overall population of 65.1 million: England (population: 54.7 million), Scotland (5.3 million), Wales (3.1 million) and Northern Ireland (1.8 million) (ONS 2017). In 1997, Scotland and Wales held referendums which determined in both cases the desire for self-government. In the case of Wales, this led 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 1 July 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.

Wales is a small nation to the west of England with an ancient Celtic culture and a thriving separate language, with c.20% of the population able to speak Welsh. Its south coast became pre-eminent during the UK's Industrial Revolution due to coal mining and heavy industry; however, Wales is mostly rural and suffers from post-industrial poverty, seasonal employment and the dependence on the public sector for a significant proportion of jobs. Away from the south, the country is sparsely populated with resilience and interconnectedness of the transport infrastructure an issue. Hence, its communities—specifically its schools and teachers—suffer from the perils of isolation, like other countries actively addressing the technology skills gap such as New Zealand (Bell et al. 2014), Sweden (Rolandsson and Skogh 2014) and Israel (Gal-Ezer and Stephenson 2014). Apart from the south-east corner (including its capital city Cardiff) and the regions bordering England, the rest of the country is formally designated by the European Union as a so-called “Convergence area”, meaning its per-capita GDP is less than 75% of the European Union average.

The Welsh education system

Wales obtained a range of devolved powers from the UK Government in 1999. Prior to this, 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 (OECD 2014). 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). Evans (2015) presents a detailed analysis as to the causes of this, citing a multitude of policy changes and poor interventions, evidenced by a hard-hitting report from the OECD (OECD 2014), supported by a detailed analysis in Egan (2017).

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 (Evans 2015), with a range of issues related to the teaching of ICT (Barnes and Kennewell 2017).

With devolved government comes fiscal autonomy; the correlation between money and performance is an obvious target for critics, who point to a growing spending shortfall between Wales and England. The average spend per pupil in Wales in 2000–2001, just after devolution, was more than every region of England apart from the large metropolitan areas of London, the West Midlands and the North West, all of which benefit from their vast economies of scale. However, since then, the gap between the education budgets per pupil between Wales and England has steadily grown by about 1% per year.

Curriculum reform in Wales

In light of the challenges within Welsh education, there have been a number of reviews commissioned over the past 5 years to identify the causes of these failures and to make recommendations to improve the education system in Wales. We reflect here on the two recent major reviews which are particularly pertinent to the emerging reform of computing education in Wales, providing wider context for this national case study.

Review of the ICT curriculum

In January 2013, the Welsh Government initiated a review to consider the future of computer science and ICT in schools in Wales. Its primary thesis was that ICT in schools needed to be re-branded, re-engineered and made relevant to now and to the future, with computer science being introduced at primary school and developed over the course of the curriculum so that learners can progress into a career pathway in the sector; relevant skills, such as creative problem-solving, should be explicitly reflected in the curriculum; and revised qualifications should be developed in partnership with schools, higher education and industry.

The ICT Steering Group published its recommendations in October 2013, highlighting the importance of computing and digital competencies in a modern, challenging and aspirational national curriculum (Arthur et al. 2013). Its headline recommendations were grouped into three main themes: curriculum and qualifications; teacher training and professional development; and infrastructure and monitoring. The report recommended that ICT be replaced from Foundation Phase (3–7-year olds) onwards by a new subject named Computing. This subject would disaggregate into two main disciplines: Computer Science on the one hand and Information Technology on the other; and this new subject should be integrated into the curriculum as the fourth science, served by a mandatory programme of study, and receive the same status as the other three sciences, linking back to the recommendations from the first Royal Society report (Royal Society 2012). It further recommended there to be a clear distinction between digital competencies and the discipline of computing by proposing a statutory cross-curricular digital competency framework to work alongside existing frameworks for literacy and numeracy. There was also a strong focus on supporting the ICT teaching profession in Wales, particularly around initial teacher education and incentivising routes into the profession, as well as raising the profile and importance of career-long professional development and entitlements to in-service training.

In the context of the new computer science curriculum introduced in England from September 2014, the ICT Steering Group's report was well-received by its national and international stakeholders, addressing the specificity of the educational challenges in Wales, as well as providing a broad and balanced curriculum for all learners, from cross-curricular digital competencies through to computer science. Whilst aspects of the recommendations around digital competencies had been readily adopted, everything relating to curriculum and qualifications was pre-empted by the announcement in March 2014 of a wholesale independent review to provide recommendations to inform the development of a new Curriculum for Wales.

Review of the national curriculum

In March 2014, Professor Graham Donaldson, a former chief inspector of schools in Scotland, was appointed by the Welsh Government to conduct an independent review of curriculum and assessment of the entire curriculum in Wales. This followed on from a number of previous national-level consultations and reviews, including the 2013 review of the ICT curriculum.

The review—"*Successful Futures: Independent Review of Curriculum and Assessment Arrangements in Wales*"—was published in March 2015 and proposed significant and fundamental changes to the education system in Wales (Donaldson 2015). Whilst identifying a number of strengths in the current education system—for example, the early years Foundation Phase and the commitment to Welsh language and culture—the report identifies significant shortcomings in the current curriculum arrangements, which essentially remain as devised in 1988 (when it shared a national curriculum with England, predating the devolved education system). The report argues that the curriculum has become overloaded, complicated and, in many parts, outdated. It identifies four overriding purposes for the curriculum, recommending that the entirety of the school curriculum should be designed to help all children and young people to become *ambitious, capable learners, ready to learn throughout their lives; enterprising, creative contributors, ready to play a full part in life and work; ethical, informed citizens of Wales and the world; and healthy, confident individuals, ready to lead fulfilling lives as valued members of society*.

Reflecting the importance of digital skills, the review added digital competency as a new third cross-curricular responsibility, with literacy and numeracy. With the structure of Foundation and Key Stages disappearing, individual curriculum subjects would be replaced with six broader "Areas of Learning and Experience" (AoLE): Expressive Arts; Health & Well-being; Humanities; Languages, Literacy & Communication; Mathematics & Numeracy; and Science & Technology. Within these AoLEs, subjects should "service the curriculum but not define it" (Donaldson 2015), and all teaching and learning would be directed to achieving the four curriculum purposes. With this move away from single subject disciplines to more thematic areas of learning and experience, diverging from the curriculum model in England, there are a number of similarities to Scotland's *Curriculum for Excellence* (Scottish Government 2004).

Successful Futures adopted the recommendations of the 2013 review of the ICT curriculum (Arthur et al. 2013), in particular recognising the importance of separating digital competencies from the curriculum subject of computing, as well as significant opportunities for interdisciplinary learning across the STEM subjects. The transition from ICT was further reinforced by new guidance issued by Estyn, the education and training inspectorate for Wales, articulating how ICT would be inspected until the Digital Competence Framework is fully implemented (Estyn 2017). Computer science would now sit within a new Science & Technology AoLE with a clear strand of learning from the start of compulsory education through to qualifications at 16 and 18 (Crick and Moller 2015). Furthermore, it recommended a programme of professional learning to be developed to ensure that the implications of the review for the skills and knowledge of teachers are fully met. The curriculum review was cautiously well-received by the education community and the media in Wales, albeit with significant detail remaining to be seen in implementation, resourcing and timescales.

Ongoing reform

The publication of *Successful Futures* was quickly followed by a review of initial teacher education in March 2015 (Furlong 2015), alongside the Welsh Government's announcement of a new professional learning model for the education workforce, complementing the outcomes from the previous reviews, providing a framework for excellence in teaching and leadership and continuing professional development to support teaching professionals in shaping and delivering the new curriculum going forward (Welsh Government 2017).

Wales is currently implementing an innovative practitioner-led, co-produced curriculum reform model, with major changes to appear from 2019 onwards. As indicated in a recent national OECD review (OECD 2017), the commitment to improving the teaching and learning in Wales' schools is visible at all levels of the education system, most notably a shift in the approach to school improvement away from a piecemeal and short-term policy orientation to one with a long-term vision involving key stakeholders. In line with the recommendations of this review, the focus of continuing reform is based on developing a high-quality teaching profession, making leadership a key driver, ensuring equity in learning opportunities and student well-being, and moving towards a new system of assessment, evaluation and accountability that aligns with this new curriculum approach.

Technocamps: a university-based engagement model

Since 2000, Swansea University—as elsewhere across the UK—suffered a steady decline in the number of students enrolling in computer science, with the worst effect on the already-dwindling numbers of female students. In an attempt to address this worrying trend, the University reached out to local secondary school ICT teachers. However, there was positive resistance; for reasons explained later which did not apply to teachers in England, teachers in Wales felt over-burdened and disinterested in exploring any perceptions of inadequacy in the curriculum and their delivery (Crick and Sentance 2012; Brown et al. 2013).

As it was proving impossible to influence schools and their ICT teachers directly, Technocamps was created in 2003 to promote computing amongst their pupils. This was a programme of engaging interactive computational workshops taking place on the university campus whose ultimate aim was to subtly re-introduce computer science into the ICT curriculum by generating the demand from the students.

Originally developed at Swansea University, Technocamps hubs have since been created at all of the universities across Wales, thus offering full national coverage.

Teachers in Wales were happy to "treat" their classes to these "day out" activities; but they were then faced with the prospect of satisfying their pupils' newly discovered passion for computing, programming and computational thinking by introducing "Technoclubs" as lunch-time extra-curricular activities in the school. With substantial help, resources and guidance from Technocamps—along with the fact that in many cases students appeared to be more technically informed and digitally literate than their teachers—these clubs have flourished, and the impact of Technocamps in changing attitudes in Welsh schools regarding ICT and computing has been widely acknowledged, both by the Welsh Government, as well as by the teaching community in Wales. The spectrum of Technocamps activities is presented in detail in Crick and Moller (2015); here we assess its wider strategic impact.

Measuring impact: Wales divided

In 2010, based on long-term empirical data regarding its effect on school children's attitudes towards computer science and technology careers—as well as that of their teachers—Swansea University was awarded £3.9 million funding towards a £6 million 4-year project (with the remaining £2.1 million generated through matched funding from the university) by the Welsh Government under the EU's European Social Fund (ESF) Programme. This funding provided the necessary support and infrastructure to run Technocamps with regional hubs at the Universities of Aberystwyth, Bangor and South Wales. Due to EU funding restrictions, Technocamps was prohibited from providing any support (specifically, resources for workshops, teacher sessions, Technoclub support, etc) to schools outside of the socio-economically deprived Convergence Area in the west (see Fig. 1). Thus, the project could not work with schools in the eastern region of Wales—including its capital city Cardiff—bordering England.

Whilst an unfortunate artefact of the European funding, a fortuitous side effect of this restriction was that it allows for a true assessment of the interventional impact of Technocamps, as the nation was invariably divided into two halves: West Wales received the full Technocamps experience, whilst East Wales (including its capital city, Cardiff) did not.

Cardiff is also the primary base of Computing At School (CAS) in Wales; as presented in "A brief history of computer science education in the UK" section, CAS has been widely recognised for their role in reforming the computing curriculum in England (Brown et al. 2014). Since 2010, Technocamps has supported CAS in promoting their teacher-led initiatives, specifically the local/regional CAS hubs and the Network of Excellence model (Sentance et al. 2012; Brown et al. 2014; Sentance et al. 2014).

In 2012, CAS Wales was awarded a grant of £70,000 from the Welsh Government to support the initial development of a Network of Excellence model of teacher-led activity across Wales, complementing the millions of pounds granted to CAS by the UK Government for this initiative in England. Despite the financial

Fig. 1 Wales divided, with only the shaded region receiving Technocamps' support

support for CAS Wales, and the networking support it offers teachers in Wales, the CAS model (Sentance et al. 2014)—so successful in heavily populated and geographically dense areas of England—has never managed to gain traction in Wales. For example, whilst CAS hubs across the UK are generally run *by schools for schools* (or rather, *by teachers for teachers*) abiding to the principle of the teacher-led approach (Sentance and Csizmadia 2017), virtually all of the CAS hubs across Wales rely on the leadership offered by the university academics who manage the various Technocamps hubs. Sentance et al. (2014) demonstrate the effectiveness of the Network of Excellence model in England where critical masses of competent and engaging teachers are found in densely populated regions; but in Wales, teachers have generally not been as self-organising compared to England to promote the wider CAS agenda to support curriculum reform and build a teacher-led community. This is partly attributable to the uncertainty surrounding ICT curriculum reform in Wales over the past 5 years (Crick and Moller 2015), especially compared to the highly visible reforms in England; but even this uncertainty is fed by the reluctance on the part of Welsh Government to introduce radical change for which the teaching community is unprepared (Barnes and Kennewell 2017).

In contrast to this, an independent review of Technocamps activity in the (socio-economically disadvantaged) Convergence region of Wales carried out for Welsh Government estimates that 5% of its secondary school-aged youths engaged with Technocamps through Workshops, and that more than a quarter of the secondary schools in the region have established Technoclubs (Wavehill 2015). Furthermore, the new GCSE and A-Level Computer Science qualifications (with its exams taken at ages 16 and 18, respectively)—which has had poor uptake in Wales due to the lack of clarity surrounding curriculum reform—are now starting to be adopted by an increasing percentage of these schools, whilst schools outside of the Convergence area (and outside the reach of the Technocamps ESF-funded project) continue to deliver the ICT curriculum as is. In an online survey carried out amongst all Welsh ICT teachers in February 2015, when asked to rate from 1 (very little) to 10 (very much) the extent to which Technocamps created an increase in the teaching of computer science, the average response was 7.3 with over 80% of the respondents (26 out of 32) giving a top-half grade.

Although it could not operate within the non-Convergence area of Wales, Technocamps promoted all of its extensive online computing resources to all schools outside the Convergence area of Wales, and supported the activities of CAS Wales in promoting its Network of Excellence model of practitioner-led school-based activities throughout Wales. However, despite the ongoing efforts of CAS Wales, there are few active and sustained school-based computing clubs that are not inside the Convergence area and established due directly to Technocamps workshops and follow-up engagements (Crick and Moller 2015).

In further support of this claim, we consider the following national example. The Annual Technocamps Robotics Competition is open to all schools across Wales, with increasing levels of engagement over the past 5 years. However, every single one of the 43 teams entered in the 2013 competition held near Cardiff travelled in from a Convergence area Technoclub formed on the back of Technocamps workshops and follow-up engagements with Technocamps initiatives. By the time the competition returned to Cardiff in 2017, the Technocamps hub at Cardiff University had become increasingly active (being freed from the restrictions of the European-funded project) and there was a healthy number of Cardiff-based Technoclubs taking part in the competition. However, these still did not represent a significant proportion of the teams competing, and every one of these clubs was heavily subsidised and supported by Technocamps. Most of the schools entering teams were from the traditional Technocamps heartland in the West of Wales and mostly able to take part without any further Technocamps intervention.

The above provides clear evidence that the Technocamps model of intense direct engagement through campus-based workshops, in conjunction with teacher CPD and support, is crucial for success in promoting the uptake of the discipline of computer science in Wales. The lack of confidence and isolation felt by the teacher community in Wales means that computing clubs have only arisen—and will likely only continue to develop—through direct involvement of and engagement with initiatives such as Technocamps. In comparison to similar challenges in Scotland (Cutts et al. 2017), this situation might only change through clarity regarding curriculum reform, as well as sustained long-term funding to provide professional development for the teachers across the whole of Wales.

Teacher impact

In Spring 2015, as part of the Welsh Government's *Learning in Digital Wales* funding programme, an anonymous online survey was carried out. A link to the survey was sent out to headteachers and ICT/Computing subject leaders in every secondary school across Wales. The survey set out to measure the extent to which schools and teachers: (i) understood the (need for) proposed changes to the computing curriculum; (ii) felt the need for support to face these changes; and (iii) recognised the various organisations that were providing such support.

Responses to the survey were submitted from over a third of such schools (75 out of roughly 220 schools), and these depict Technocamps in a positive light. In particular, only one respondent claimed to be unaware of Technocamps, whereas over 85% of respondents were not only aware of Technocamps but were actively benefitting from its various activities. In contrast, only 60% were aware of or benefitted from CAS, whilst 19% were unaware of CAS. The lack of awareness and benefits of CAS is due, in no small part, to the Anglo-centric nature of CAS' funding and bulk of activity. However, even flagship national technology resources developed by the Welsh Government and promoted heavily within schools were not as well regarded: whilst every respondent was naturally aware of its national online learning portal *Hwb,*[4] only 57% reported that they benefit from it; and a full 24% were unaware of their regional educational consortium with only 51% benefitting from it. Many of these outcomes have been validated in a wider survey by Sentance and Csizmadia (2017) on teachers' perspectives in England and the various challenges and strategies surrounding computing curriculum reform, with clear themes from teachers on the frontline (Sentance and Waite 2018).

Government and policy impact

The impact described above that the various Technocamps initiatives has had on changing perceptions in schools—both pupils and teachers—has also translated into impact on Welsh (and UK) Government thinking and policymaking in the area of computer science education, teacher training and professional development, offering potential transferability to other nations and regions. For example, this has resulted in working closely with policymakers to co-create national scale educational outcomes, as well as ensuring the wider public understanding of this work. This is of particular importance during any election period; Technocamps was regularly cited in government communications and the UK national press[5] as a key organisation in developing digital skills in Wales, highlighting the importance of these intervention in developing digital skills to support the long-term economic aspirations of the nation.

[4] http://hwb.wales.gov.uk.

[5] For example: http://www.huffingtonpost.co.uk/carwyn-jones/skills-for-the-jobs-of-today-and-tomorrow_b_9767130.html.

Conclusions and lessons learnt

When establishing a model for viewing school computer science education, it is apparent that there is substantial diversity between school education systems (Snyder 2012), and this can create obstacles when trying to understand progress made in one country and potentially replicate it in another (Hubwieser 2013); this is also pertinent to the devolved (and diverging) educational systems of the UK.

We are now seeing a number of successful initiatives, activities and interventions which may prove useful to other nations reforming their curricula, especially in the context of developing broader societal digital competencies. However, there remain significant challenges, particularly around improving the wider public perceptions of the disciplines and its inherent educational and economic value, the quality and utility of qualifications available in this space, as well as how to upskill the entire teaching community of Wales. This is the profound and long-term challenge—certainly not unique to Wales—that has to be recognised and addressed before a number of nations see the type of computer science education that is sustainable and does not actively dissuade students from progressing onto degree-level study or opting for diverse technology-based careers.

Through this national case study for Wales, and in particular evidenced through the Technocamps project and model, we have identified a number of overarching themes that frame the "lessons learnt". This provides for potential replicability as a case study of a national engagement model for other similarly sized countries and regions of a comparable geo-political composition to Wales that are on a similar computer science curriculum reform journey.

Two overarching themes are apparent; firstly, such effort has to be viewed as a *multi-pronged approach*, requiring an overarching holistic strategy, working collaboratively with teachers, pupils, schools, parents, local and national government, etc. For example, with Technocamps, it was clear that through the European Social Funds project, funding directed at young learners was not enough: there is a wider ecosystem of activities and engagement, providing an opportunity for partnerships, co-design and co-production with key actors and stakeholders. Secondly, there is a need to overcome the challenges of recurrent funding and support to ensure *long-term sustainability* of the interventions. As this invariably requires a systematic change, single interventions to a single cohort of students are clearly not enough; it has to be a multi-year, co-ordinated effort (Repenning 2018). Furthermore, any new initiatives must address local and regional needs whilst at the same time maintaining strategic coordination at the national level; as argued, the long-term delivery model of Technocamps has had a clear impact on engagement, upskilling and the wider perception changes in ways that other less intense and sustained models have failed.

Through these two overarching themes, we have identified four "lessons learnt":

- *The importance of active and sustained support of all practitioners* In a country which imposes isolation for teachers in schools, simply providing resources is not enough. Network building is difficult, especially for geographically isolated practitioners. To support the development of sustainable communities of practice, as well as the wider theory of change and culture required for a successful curriculum reform process, active support and engagement is key.

As a university-based model with hubs in every university in the country, Technocamps has the necessary geographical reach to support practitioners throughout the country. It has been working through its Technoteach programme to create a small but critical mass of qualified teachers, again necessarily through a programme of direct and intense intervention.

The Technoteach model of direct intervention will remain necessary for some time; but in the long run, with a growing community of confident and capable teachers, we hope eventually to arrive at a situation in which the practitioner-led CAS model will be as effective in Wales as it has been in England.

- *It is not just about access to resources (and not just about kit)* As part of the sustained and long-term Technocamps intervention, it has been clear that it is not just about providing access to resources—physical and virtual—and certainly not just about providing access to the latest tool or technology. If you are attempting to transition an existing body of professional teachers (as well as recruit new ones), a primary focus has to be on building a research-engaged profession, prioritising the development of both computer science subject knowledge and pedagogic knowledge, as well as emerging research and practice on progression and assessment. Again, we have seen through Technocamps activities the importance of moving from discrete in-service training to continual professional development model.
- *Embrace policy and public engagement* Wider policy and public engagement is crucial at a number of levels, from directly focusing on education and skills through to wider science, innovation, infrastructure and digital economy policy. Alongside Wales and the rest of the UK, a number of other jurisdictions have directly linked to wider national strategic economic aspirations, directly lobbying for policy change and identifying "hooks" for digital and emerging technology skills. Furthermore, this provides a wider platform for stakeholder engagement, through working with industry for various interdisciplinary technology careers (especially important for post-industrial regions like Wales), as well as media and general public engagement to change the wider perceptions of the discipline and why it should be available to all—as well as supporting a wider drive for a digitally competent and capable citizenry. It is important not to just be seen as "computer scientists moaning about the lack of computer scientists" i.e. a special-interest lobby group, but directly linking to wider strategic national policies.
- *Accept the bilingual/multi-lingual/cultural challenges* For Wales, a nation with a thriving national culture and language alongside English, there is a legal and national imperative to support a bilingual economy, underpinned by the relevant education and skills. For other countries on a similar curriculum reform path, in which English may be a second language, this will pose challenges around availability of tools, resources and support. Whilst English is the de facto international language of science—and most likely programming—significant time and resources have to be invested in developing the necessary support

structures to support native language (or multi-lingual) training and delivery. Nevertheless, in doing so, there is a significant opportunity to develop new digital cultures, with benefits for learners, practitioners and the wider economy.

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