Raspberry Pi Foundation

Understanding computing education

Volume 2

Theme: Equity, diversity and inclusion in computing education

Raspberry Pi Foundation Research Seminars

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Foreword

In May 2020, the Raspberry Pi Foundation held its first online research seminar on computing education. The format was simple: a presentation from a researcher, followed by breakout groups, and then a whole-group question and answer session. It was a great success! From that point onwards, we have continued to host Tuesday seminars, first fortnightly and then monthly. By the end of 2021, we will have hosted 22 seminars on a range of topics across the broad subject of computing education. Videos and presentations from all our seminars can be found on our previous seminars page[1].

To accompany the seminars, we publish the proceedings for each set of seminars. This is the second volume and contains papers from five of the seven great seminars held from January to July 2021. The overarching theme that links all the seminars is the importance of **equity, diversity and inclusion in computing education**. The series was hosted in partnership with the UK's Royal Academy of Engineering; bringing computing education to all young people, with a focus on equity, is incredibly important to both our organisations.

The first chapter is a fantastic introduction to this topic, with Tia C. Madkins and Nicol R. Howard describing their work on equity-focused teaching in the USA. They highlight asset- and strengths-based approaches to teaching computing science and the role of families and communities in promoting equity. The second chapter, from Hayley Leonard and Thom Kunkeler, describes a UK-based project to better understand the perspectives of learners from lower socioeconomic backgrounds on computing and digital literacy. This chapter also highlights the complexity of the term 'digital divide' and what it encompasses. The third chapter relates to our first seminar, which was delivered by Peter Kemp and Billy Wong, and considers issues around gender balance in post-mandatory computer science classes, along with an analysis of the disparity. The fourth chapter focuses on inclusion and addresses the needs of students with disabilities in computer science education in school: Maya Israel describes four principles for equity-focused instruction, alongside how Universal Design for Learning (UDL) can be used to frame our understanding of computer science education. From our July seminar, Ron Eglash shares his wonderful work on computing for generative justice, reflecting the inspiring seminar he gave on heritage algorithms, and shows us how relating traditional practices and art to STEM education can bring value back to the community through a 'circular economy'. And finally, we have a bonus report about culturally responsive pedagogy relating to a Raspberry Pi Foundation project that we're sure you'll find interesting!

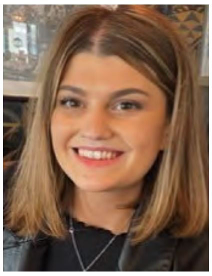
We are very proud of our seminar series and that it has generated wide and international interest. Through the talks, blog posts, and proceedings, we hope to develop a community of researchers and practitioners who can share their perspectives and experiences, with the ambition of ensuring that the great research we showcase in these seminars can translate into practice.

We hope you enjoy reading these chapters as much as we enjoyed putting this volume together. Do let us know your feedback, and we look forward to bringing you Volume 3!

Sue Sentance, Chief Learning Officer
Raspberry Pi Foundation,
October 2021

[1] https://www.raspberrypi.org/computing-education-research-online-seminars/previous-seminars/

Information about the authors (in alphabetical order)



Meggie Copsey-Blake
(King's College London, UK)

Meggie Copsey-Blake's research focuses on the experiences of students of marginalised groups in UK schools and universities, especially through examining discourses of identity and intersectionality. Meggie is assisting with various research projects on educational inequalities, and is part of the SCARI Computing (Subject Choice, Attainment & Representation in Computing) project at King's College London. The SCARI Computing project is funded by the Nuffield Foundation, and aims to widen participation and improve gender diversity in computing education across secondary schools in England.

Ron Eglash
(University of Michigan, USA)

Dr. Ron Eglash obtained his B.S. in cybernetics and his M.S. in systems engineering at UCLA. He received his doctorate at UCSC in History of Consciousness under Donna Haraway. Ron was a faculty member in the STS department at RPI for two decades; he is now a Professor in the School of Information at the University of Michigan. He is known for his monograph African Fractals: modern computing and indigenous design; his anthology Appropriating Technology; and his software suite, Culturally Situated Design Tools. His work combines analysis of the social dimensions of science and technology with innovations at the intersections of anti-racist activism and computational design.

Jessica Hamer
(King's College London, UK and the Institute of Physics, UK)

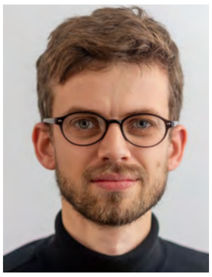
Dr Jessica Hamer is a Research Associate in the SCARI Computing project (Subject Choice, Attainment and Representation In Computing) at King's College London and also works within the education team at the Institute of Physics. Her research explores the barriers young people face when it comes to subject choice, especially in STEM subjects. She has a PhD in palaeoclimatology and spent over 10 years as a secondary physics teacher and teacher trainer.

Nicol R. Howard
(University of Redlands, USA)

Nicol R. Howard, Ph.D. is an associate professor and associate dean in the School of Education at the University of Redlands. Dr. Howard is also co-director of the Race in Education Analytics Learning Lab (REAL Lab), and a co-editor for the *Journal of Computer Science Integration*. Her research focuses on STEM and computer science equity, digital equity, and parent involvement. Recently, she has been examining family-school partnerships and the racialized experiences of Black girls and families in mathematics and computer science classrooms. Dr. Howard is currently PI on a grant focused on equitable practices that reimagines university and district partnerships in their preparation and support of future educators. Her concern for equity in education also led to a co-authored book: *Coding+Math: Strengthen K-5 Math Skills with Computer Science*.

Maya Israel
(University of Florida, USA)

Maya Israel, Ph.D. is an associate professor of Educational Technology and Computer Science Education at the University of Florida. She is also the research director of the Creative Technology Research Lab. Prior to entering higher education, Dr. Israel was a special education teacher. Her research focuses on strategies for supporting academically diverse learners' meaningful engagement in STEM, with emphasis on computer science education and Universal Design for Learning (UDL). She is currently PI on several grants including a National Research Foundation project to address ways to make computer science education more inclusive to students with disabilities. Dr. Israel also works with multiple school districts on systemic and classroom strategies to more equitably include students with disabilities in K-12 computer science education initiatives.



Peter Kemp
(King's College London, UK)

Dr. Peter Kemp is Lecturer in Computing Education at King's College London, where he runs the PGCE in Computing. His research interests are centered around digital equity, digital arts education, curriculum design, and creativity and computing. His Ph.D. looked at the intersection of the computing and media studies subject domains in the development of student digital creativity. He has published multiple reports on the changing landscape of computing education in England. In his spare time he helps run 3Dami, a non-profit organisation that teaches 3D digital animation to school students.

Thom Kunkeler
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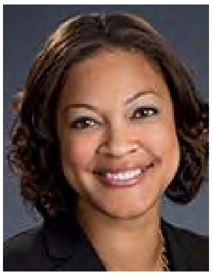
Thom Kunkeler is a Research Assistant at the Raspberry Pi Foundation. Prior to this, he graduated from the University of Amsterdam with a Research Masters in Social Sciences. His earlier research focused on socioeconomic inequality, racism and police violence, with a Masters thesis detailing social movements and political change during the civic unrest of 2014 in Ferguson, Missouri. At the Raspberry Pi Foundation, his research interests translate into understanding inequity in computing education, access to digital technologies, and the development of digital capital among young people.

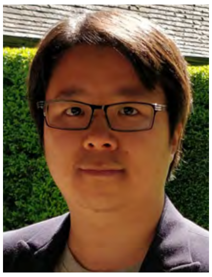
Hayley Leonard
(Raspberry Pi Foundation)

Dr. Hayley Leonard is a Research Scientist at the Raspberry Pi Foundation. She was previously a primary school teacher and a lecturer in Psychology, where her research focused on how different factors affected children's development and learning, especially those with special educational needs. At the Raspberry Pi Foundation, her work aims to understand factors affecting effective teaching and learning in computing education. She is particularly interested in issues of diversity and inclusion, and how best to help young people to access and fully engage with computing.



Tia C. Madkins
(University of Texas at Austin, USA)

Tia C. Madkins, Ph.D. is an assistant professor in STEM Education and Department of Curriculum and Instruction in the College of Education and a faculty research affiliate with the Population Research Center and the Center for the Study of Race and Democracy at The University of Texas at Austin. Her research focuses on supporting teachers to design inclusive STEAM + computing classrooms and engage equity-focused pedagogies with minoritized students, especially Black girls.



Billy Wong
(University of Reading)

Dr. Billy Wong is an Associate Professor at the Institute of Education, University of Reading. His areas of research are educational identities and inequalities, especially in the context of higher education and STEM education. His publications have explored the changing views and experiences of university students and staff, as well as young people's science and career aspirations. He was part of the team which developed the concept of 'science capital'. He is author of Science Education, Career Aspirations and Minority Ethnic Students (2016, by Palgrave) and his latest book, The ideal student: Deconstructing expectations in higher education, was published in May 2021 (Open University Press).

Tia C. Madkins (The University of Texas at Austin)
Nicol R. Howard (University of Redlands)

Equity-focused teaching in K-12 CS: strategies for teachers, teacher educators, and districts.

Equity-focused teaching in K-12 CS: strategies for teachers, teacher educators, and districts

Tia C. Madkins (The University of Texas at Austin)
Nicol R. Howard (University of Redlands)

Abstract

In this chapter, we aim to support practitioners in understanding what equity-focused teaching and learning can look like within K-12 computer science learning settings. We unpack key constructs, such as equity and minoritized learners, to offer context for how we identify learners and how we define equity. In providing an overview of a justice-oriented approach to computer science education, along with our rationale for how and why prioritizing asset- or strengths-based approaches are essential in this work, we demonstrate how practitioners can shift the focus in computer science learning further towards justice-oriented approaches. After explaining what it means to use a justice-oriented equity lens in computer science teaching and learning, we offer key considerations when integrating computer science and share how to engage families and communities. In sharing, we hope to provide practical insights and guidance to practitioners for engaging in equity-focused teaching in Key Stage 1-4 and K-12 computer science education. Resources for further learning are also included.

Introduction

We write this chapter amid the COVID-19 pandemic, which continues to impact learners of all ages, families, and our educational systems in more ways than we could have ever imagined. As such, we begin by giving gratitude to all educators and the learners and families these educators work with across learning settings globally. Teaching and learning in the COVID-19 era have (hopefully) increased our awareness of and attention to educational inequities; using equity-focused pedagogical strategies is one way we can respond to these inequities to meet the needs of all learners—especially minoritized learners. Much educational research has focused on equity-focused teaching and learning in general or across specific content areas (e.g., Martell & Stevens, 2017; Titu et al., 2018), and there is a growing body of research focused on equitable computer science (CS) education (e.g., Fields et al., 2018; Ryoo et al., 2015). In our previous work, we have provided an overview of the distinctions between common approaches to equity-focused teaching and learning, as well as specific suggestions for STEM teacher educators (e.g., Madkins et al., 2020; Madkins & Morton, 2021). Here, we focus on how educators, teacher educators, and school district personnel (e.g., instructional coaches, CS instructional coordinators, research associates, etc.) can engage in equity-focused CS teaching and learning. We aim to support our readers in understanding what equity-focused teaching and learning can look like within CS learning settings. We also share why stakeholders should use these strategies with learners in Key Stage 1-4 in classrooms in the United Kingdom or similar systems globally and K-12 classrooms in the United States.

To this end, we share our expertise as U.S.-based researchers and former classroom educators related to engaging in equity-focused work in CS learning environments with attention to minoritized learners, knowing that this work is important for *all* learners. We recognize that many educators work with learners who are multiply-marginalized and cannot provide expertise related to working with learners with disabilities (see Israel in this volume for supporting learners with disabilities). First, we define key constructs in preparation for a discussion about justice-oriented approaches to computer science education. We provide a brief overview of using equity pedagogies, key considerations for integrating CS with an equity lens, and how to engage families and communities. In doing so, we hope to provide practical insights and guidance to practitioners for engaging in equity-focused teaching in K-12 computer science.

Constructs defined

We are former elementary school teachers (Key Stage 1-2; K-5 in the U.S.) and have worked with children of all ages in both formal and informal learning settings (e.g., classrooms, schools, after-school programs, summer enrichment programs). We are also both researchers and university-based teacher educators who focus on supporting pre-service and in-service teachers to engage equity-focused teaching strategies and design inclusive STEM classrooms (i.e., classrooms where learners' multiple identities are honoured). As such, the terms we use to identify learners and how we define equity are grounded in these experiences and our asset-based beliefs about the communities we have worked with over time.

Minoritized learners

Rather than referring to students as Students of Colour, which is a commonly used phrase to refer to children who are from racial and ethnic minority groups, we use the term *minoritized learners*. By using this term, we highlight the power dynamics and racial hierarchies influencing communities who are of the global majority (Lim, 2020), yet in dominant narratives are minoritized (e.g., *minority students, racial minorities*). Our use of *learners* rather than *students* pushes back against traditional narratives about how we define students using white middle class norms and signals that all children are learning no matter where they are—in or out of schools (Adair & Sánchez-Suzuki Colegrove, 2021; Madkins & Morton, 2021).

Equity

As evidenced in our seminar session, educators, researchers, and other stakeholders define the term, *equity*, in varied ways. Individuals typically understand *equity* in ways that reflect equal access and achievement, which are important ideas and practices if we are to achieve equity within CS education. This includes, but is not limited to, meeting all learners' needs with resources (programming software, laptops, etc.), providing all learners with access to high-quality CS instruction, or finding ways to remedy disparate academic achievement outcomes based on race, ethnicity, social class, or other identity markers. These definitions align more with *equality*, which is common not only within our society (A. E. Casey Foundation, 2020), but is prominent in educational research and practice (O. Espinoza, 2007; Gutiérrez & Jaramillo, 2006). However, we "*advocate for the use of equity-focused teaching and learning as an essential practice within computer science classrooms*" and use a social justice equity lens (Madkins et al., 2020, p. 1). Thus, we now turn our attention to operationalizing equity-focused teaching as we discuss a justice-oriented approach to computer science education.

A justice-oriented approach to computer science education

A justice-oriented approach requires three components: 1) prioritizing asset- or strengths-based approaches that centre learners, families, and communities; 2) using an equity lens that moves beyond access and achievement frames and instead centres social justice; and 3) empowering learners to use CS knowledge for transformation. Ultimately, a justice-oriented approach is one where learners can use their CS knowledge in ways learners themselves see fit to transform their communities and make connections to other content areas, particularly other STEM concepts. Simply put, this means we cannot define success in one way or emphasize the potential learners have for their professional futures (i.e., becoming the next big tech industry professional or only highlighting lucrative careers in CS). Rather, we allow learners to determine how they want to use the CS and STEM knowledge they develop across learning contexts *and* allow them to define what success means to them, their families, and their communities. Though it is important to make clear the multiple academic and career pathways learners might pursue and position all young people we work with as capable of engaging in CS, we must also allow them to determine their best pathways. To achieve this transformation and truly engage in equity-focused computer science teaching and learning, it is essential that we prioritize asset-based approaches and use an equity lens centring social justice.

Asset-based approaches

To engage a justice-oriented approach, an individual must identify, confront, and reject deficit thinking or narratives that are palpable within our society, schools, and classrooms (see Patton Davis & Museus, 2019 for a detailed explanation of deficit thinking). Deficit thinking means viewing learners, as well as their families and communities, as deficient or in need of repair, especially those learners who are racially, ethnically, culturally different from the individual educator, teacher educator, or other stakeholder. Examples of this include: “Black students have a hard time learning computer science, so it is best not to give them too much challenging work.” Or: “The families of my students who do not speak English do not care about them doing well in school.” These ideas are not only unfounded and not true—but are grounded in racist stereotypes and assumptions about the inferiority of racially, ethnically, gendered, or classed minoritized communities (Madkins & Morton, 2021; McGee, 2020). When we hear them, or think about them implicitly, we must acknowledge these ideas and reject them no matter who we are. Instead of viewing learners as deficient individuals who we need to “fix” in our classrooms, we use strengths-based approaches where we as educators learn to recognize, draw, and build upon learners’ strengths. Ways we can do this include drawing upon learners’ linguistic strengths (i.e., attending to their linguistic practices and better understanding their thinking and ideas) or finding ways to build upon learners’ lived experiences and connect them to course content. This might include inviting learners to share their personal connections to CS content and how they use CS in their daily lives. It takes time to develop a mindset that centres asset-based approaches, but it is necessary to do so since it influences instructional decision-making (i.e., curricular choices, teaching practices, and how we interact with learners).

Justice-oriented equity lens

Using a justice orientation to equitable CS teaching and learning requires us to move beyond what we normally see in terms of an equity lens in education, which is really about equality. As we mentioned earlier, this means equal access to CS course offerings within a school (i.e., not only offering CS courses to "high-performing" learners), technology tools (which we need to teach CS!), or high-quality teachers. Similarly, it means thinking beyond solving disparate outcomes related to achievement in CS, such as learners' test scores or grades, and other outcome measures, like interest in CS or pursuing postsecondary degrees in computer science. A justice-oriented approach to CS means supporting learners to have dignity-cultivating learning experiences where social justice and the development of learners' agentic selves and critical consciousness development are centred (E. Espinoza et al., 2020; Madkins et al., 2020).

This can be accomplished by using equity pedagogies (C. Banks & J. Banks, 1995). For many years, scholars who conduct research within and outside of STEM education (e.g., literacy, social studies, etc.) have shown that using equity pedagogies with minoritized learners can positively influence student learning outcomes. Equity-focused teaching practices can support learners' identity development, achievement, and conceptual knowledge development (Allen-Handy et al., 2020; Madkins & McKinney de Royston, 2019; Souto-Manning & Martell, 2017). Within CS education specifically, scholars have shown how engaging equity pedagogies in CS classrooms supports learners in increasing their interest in CS, feelings of belonging in CS classrooms and potentially as professionals, and achievement (A. Martin et al., 2017; Ryoo et al., 2013; K. Scott & White, 2013; Vakil, 2014). This body of research demonstrates how using equity-focused teaching practices can not only support learning outcomes but also further develops learners' critical consciousness. Yet, we know these practices are not commonplace. Researchers posit this is because teachers can more easily make connections between social justice issues and literacy or social studies curricula and content than they can to CS curricula and course content. (Sleeter, 2012; Young, 2010). Though it can be difficult to do this work, it is necessary. To support our readers in this area of professional development, we end by providing suggestions for how we can engage in this equity-focused work in both classrooms and in our work with families and communities. This is followed by a short resources list at the end of this chapter to support further learning.

Integrating computer science with an equity lens

Equity-focused work is important and not to be taken lightly. Educators all come to this work through different entry points on this journey; therefore, we think it is important to learn who you are and who you're in partnership with daily. Therefore, educators should prioritize deep thinking about the following when developing instruction for CS classrooms: 1) personal beliefs; 2) learners' beliefs; and 3) purpose for the lesson. Personal beliefs of educators and learners impact the learning experiences. An educator considering equity-focused CS teaching should have an awareness of how these various beliefs, and ways of knowing or thinking, impact the learning in their CS classrooms. Their own cultural lens affects their views of learners, which in turn impacts their instructional practices. To that end, it is imperative that educators know their purpose for a particular lesson. For example, is their goal to prioritize the learner's self-expression or is the focus on preparing learners for future CS courses and careers? Does the lesson enforce an arbitrary compliance to standards instead of building capacity and autonomy? Are all learners held to the same standard and expected to perform at their best? If an educator determines their purpose for a lesson is to limit self-expression and adhere to standards only, they should unpack their "why" to ensure this decision was not based upon assumptions or stereotypes about their learners. Recalibration and an assessment of how their beliefs impact their learners' access to advanced learning and opportunities for self-expression should be a regular practice (see Madkins et al., 2021 seminar video[2] for examples and further explanation).

Equity-focused CS teaching also calls for educators to support the CS identity development of learners. It is imperative that they have an awareness that power dynamics, intersectional identities, and even stereotypes can impact the learning experience in different ways. Equity-focused CS teaching also calls for educators to address the personal and sociopolitical context of CS education (Vakil, 2018). In addition to offering their own critique of technological inequities, they should provide opportunities for learners to do the same. This leads to the notion of positioning learners as change agents, whereby they become creative innovators who question the world around them and push back against fake news. To position learners as change agents, educators can begin by legitimizing learners' expertise. Designing lessons that provide opportunities for learners to share their work with the broader community is one example of how educators can legitimize their learners' expertise. For some learners, especially younger learners, it will be important for them to receive support sharing beyond the classroom. Providing avenues for them to share with parents and families is a good first step, before they share with the broader community.

Family and community engagement

Parents without backgrounds and insights into the changing landscape of technology may struggle to negotiate what roles they can play in supporting and finding learning opportunities for their children (DiSalvo et al., 2014; Roque, 2013, 2016). This does not necessarily apply to all families and parents. Remember, equity-focused CS teaching calls for an awareness of stereotypes, so it will be important for educators to check any biases and pay attention to the strengths and outside knowledge families bring to the CS learning environment. We encourage educators to connect with learners' cultural practices and lived experiences and to foster and maintain relationships with learners, families, and communities. Educators can work together with parents and the community, with purpose, to achieve a common goal: facilitating an equitable (justice-oriented) experience for learners.

Conclusion

In conclusion, we emphasize that equity-focused work is important because we cannot continue to invite learners (and in turn, their families and communities) into CS education by *only* focusing on increasing access to CS courses, development of CS knowledge, and working towards CS integration. If we, instead, engage in CS teaching and learning with a justice-oriented approach, we are more likely to invite them into a field and learning experience that they will welcome and appreciate. There is work to do within each grade level and across each key stage or grade level band within primary/elementary and secondary schools (e.g., upper primary/elementary students, middle grades, etc.). We need to have primary/elementary

[2] https://www.raspberrypi.org/computing-education-research-online-seminars/previous-seminars/#equity-focused-teaching

secondary teachers. What is most important to remember is that we as stakeholders, including classroom-based or informal educators, teacher educators, district personnel, families, and community members, are *all working together* with common goals and with purpose—supporting all learners to be successful in computer science education. We know that content and context matter, so the ways we implement equity-focused teaching practices will look different wherever learning occurs. But, we have to hold each other accountable to *actually* engage equity-focused teaching as we get better at it over time. We will be kind to each other and extend grace to ourselves and colleagues as we become more adept at this, *but we have to hold each other accountable* to do the difficult work.

Resources for further learning

Readings

Benjamin, R. (2019). Race to Technology: Abolitionist Tools for the New Jim Code. Polity. (See discussion guide available for download on website.)

Cheney-Lippold, J. (2017). We Are Data: Algorithms and the making of our digital selves. New York University Press.

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Additional resources

AI, Ain't I a Woman?[3] by Joy Buolamwini

Resources for understanding structural racism and other equity issues in our society: Comprehensive List Curated by Tia C. Madkins, Ph.D[4].

Toolkit[5] for making connections between secondary CS content and social justice issues

[3] https://www.youtube.com/watch?v=QxuyfWoVV98
[4] https://docs.google.com/document/d/1msBqreACDpFVynqA54L408tKyOepT-pXhdaL8bTtVNc/edit?usp=sharing
[5] https://docs.google.com/document/d/1x0Kgn_LHnJhzrSXU3lutGcyjooZQNgvPSXlLnmeJJDk/edit

developed by Dr. Tia C. Madkins, Nijae Jones and the Mitigating the Double Bind in CS: A Culturally Relevant Approach Research Team

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Why the ‘digital divide’ does not stop at access.

Why the 'digital divide' does not stop at access

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Abstract

Around the world, young people from socially and economically disadvantaged backgrounds are less likely to have access to a home computer and to computing at school, and are underrepresented in computing-related qualifications and careers. In the United Kingdom, although all children in school have access to a mandatory computing curriculum in some form, the uptake of computing qualifications and careers amongst those from low-income families is still low. In this chapter, we will discuss some of the complex issues that contribute to these outcomes. First, we will consider the term 'digital divide', which is used widely to discuss inequality in access to technology and digital skills. We will then introduce a framework for assessing equity in computing education that includes, but is not limited to, access. This helps us to identify key aspects of the educational journey for young people where we can most usefully focus our efforts to support those from low-income families. We will present the results of interviews we conducted with a group of young people at risk of educational disadvantage, focusing on their attitudes towards computing as a discipline and their own digital capabilities.

What is the digital divide?

According to the Close the Gap Foundation (2021), the digital divide is defined as *"the gap that exists between those who have reliable internet access and devices and those with very limited access or none at all"*. Research into the digital divide began by focusing on this concept of access, specifically to the internet, and the negative consequences on social and economic mobility that resulted from its limitation or absence (Scheerder et al., 2017). This conceptualisation leads to an expectation that improving internet infrastructure and saturation around the world would reduce the inequalities between those with and without access, but this has not been the case (Van Deursen & Van Dijk, 2019).

Understanding of the digital divide has evolved over time and now tends to be split into different levels: the first being access to technology, the second being the skills required and the use of technology, and the third being the outcomes of this use (Scheerder et al., 2017). For example, in terms of skills, the ability to use technology competently for the purposes of accessing emails or social media differs from being able to design, create and publish unique content through websites or other tools (Van Deursen et al., 2016). Those who develop the more complex skills have more opportunities to improve their economic position through a wider range of

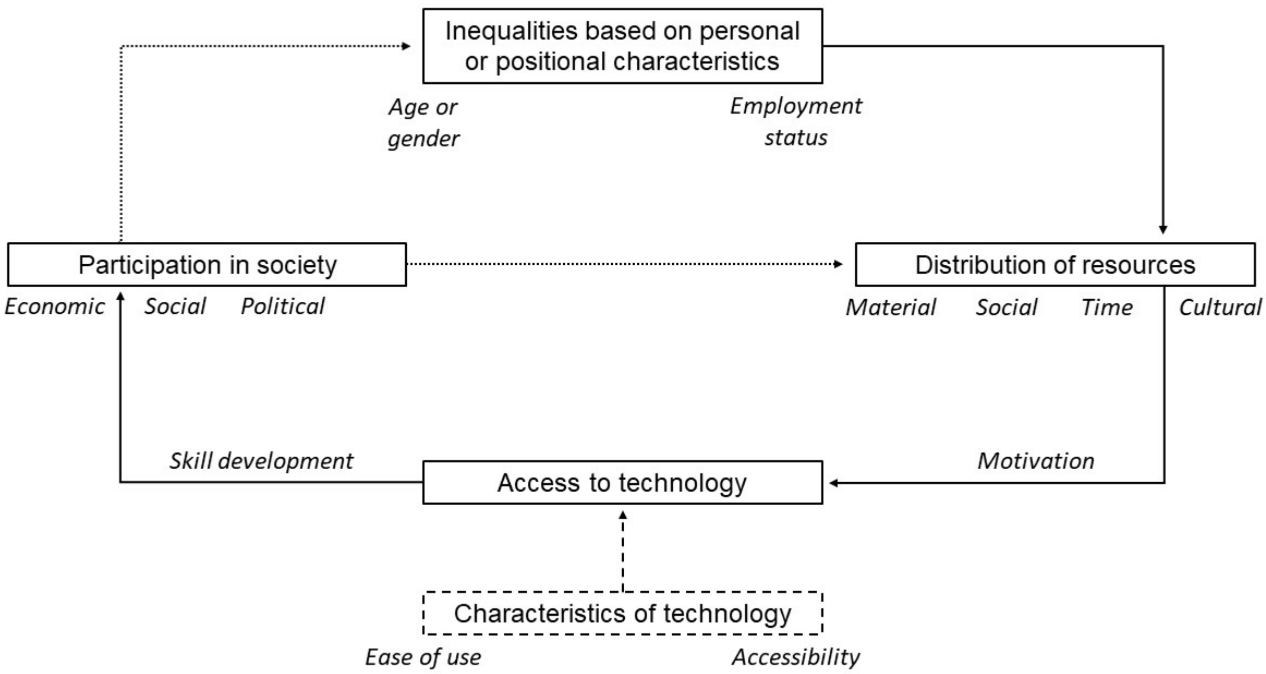

Figure 1. Representation of the Resources and Appropriation Theory (Van Dijk, 2005), highlighting the cyclical nature of inequality in technology use. Note: Adapted from Van Dijk (2013).

employment prospects. While initial access is of great importance, there are thus additional levels of the digital divide that can compound inequalities between people in society.

Van Dijk (2005) introduced the Resources and Appropriation Theory to provide an explanation of how new technologies are distributed, accessed, and used, and how this contributes to ongoing inequality in society (see Figure 1). In the first stage of the causal model, Van Dijk (2013) identifies the aspects of an individual's identity (such as age or ethnicity) and their position in society (such as employment status or the nation in which they live) which often result in unequal distribution of resources. These resources may be the physical materials themselves, but can also include having the time or skills to use these materials, the social support to learn how to use them, and the cultural environment to value and therefore want to use them.

For young people in education, their personal and positional characteristics may affect the material resources available to them even within the school environment, with schools in less affluent areas perhaps having lower quality technology. They may then also have more limited time outside of school to engage in extracurricular activities to develop their skills, and fewer role models or social connections who have access to technology and technological competence.

Van Dijk (2013) explains how access to

technologies does not only involve having the physical materials, but also the appropriate equipment to maintain access, such as relevant software, ink, etc. Furthermore, it depends on the individual's skills in using the technologies, which are influenced by the characteristics of the materials: for example, introducing a technology to a novice that involves long, complex processes and detailed knowledge is likely to result in that person giving up or not being able to advance their use of the technology. This can in turn lead to reduced participation in a number of areas of society, including economic and social mobility and political participation, which can feed back into personal and positional inequalities and produce a cycle that is difficult to break. This element of the model has implications for education, highlighting the importance of high quality instruction, introducing appropriate and incremental challenges into teaching computing, and encouraging resilience and persistence.

The model highlights the complex and cyclical nature of inequality in technological use, moving on from a simple definition of a digital divide between those who do or do not have access to technology. As outlined above, the model also provides some insights for computing education in terms of how we support young people in developing their skills and knowledge. The next section focuses on equity in computing education specifically, describing a framework developed in the United States (US) and considering its implications for the United Kingdom (UK) context.

A framework for assessing equity in computing education

In England, only 10-20 percent of students taking optional qualifications in computer science (CS) in high school are female, and those from lower-income backgrounds and of African/Caribbean descent are most proportionally underrepresented in the subject (Kemp et al., 2018, 2019). This is despite the fact that computing is a mandatory subject between the ages of 5 and 16 and therefore all children have access to a computing curriculum in some form. In the US, computing education is not mandatory but there is a similar underrepresentation of certain groups in CS qualifications (Code.org, CSTA & ECEP Alliance, 2020). There appear to be a number of structural, social and psychological barriers that prevent young people with particular personal and positional characteristics (Van Dijk, 2005) persisting with CS qualifications and careers.

Researchers in the US have developed a framework for assessing some of these barriers to equity in computing education, using the acronym CAPE to represent issues with *Capacity, Access, Participation, and Experience* (Fletcher & Warner, 2020; see Figure 2). We will now discuss each of these aspects of the framework in more detail.

Capacity and access

The first two levels of the CAPE framework represent the capacity for providing computing education, and the consequent access that students have to computing instruction. These levels reflect the distribution of resources in Van Dijk's (2005) Resources and Appropriation Theory. Schools in lower-income areas in the US tend to have fewer certified computer science teachers and funding for teacher professional development, meaning that students are less likely to be able to access high quality instruction or to be offered opportunities to study CS in their schools (Fletcher & Warner, 2020).

In England, the Department for Education has invested in computing education capacity, funding the National Centre for Computing Education which includes professional

Figure 2. Levels of the CAPE framework for assessing equity in computing education. Note: Adapted from Fletcher & Warner (2020).

development and training for teachers, the production of a freely accessible computing curriculum, and community support. The aim is to reduce or remove the inequalities between different societal groups through the school system.

However, it is important to note that, although capacity and access issues are addressed within schools, this does not overcome the inequalities present outside of school. This existing problem has recently been highlighted by the COVID-19 pandemic, during which it was clear that many young people did not have the technology available at home to be able to engage with their learning outside of school.

A report from the Sutton Trust showed that 35% of parents from low-income communities had no access to a sufficient number of devices in the home to support their children in their schoolwork, compared to 11% in higher-income schools. In addition, the number of students in schools without internet access at home was much greater for low-income families from state schools than more affluent state schools and private schools (Montacute & Cullinane, 2021). The attainment gap between those from lower- and higher-income families (e.g. Andrews et al. 2017; Tuckett et al., 2021) is evidence that inequalities outside of the classroom still affect the distribution of resources and academic outcomes of those from less advantaged backgrounds, and these inequalities have been compounded by the COVID-19 pandemic (Montacute & Cullinane, 2021).

Participation and experience

Once the building blocks of capacity for and access to computing education are in place, the CAPE framework identifies two further elements required to ensure that computing education is equitable: participation and experience. Participation refers to those who elect to study computing when it is not mandatory, while experience relates to the outcomes of this participation in terms of enjoyment, interest, learning gains, and future study and careers (Fletcher & Warner, 2020).

As described earlier, a number of groups are underrepresented in computer science in both the US and UK when the subject is elective (e.g. for higher qualifications). Research has suggested that competence and self-efficacy are important factors in maintaining interest in a subject, as well as motivating an individual to invest time and effort into it to pursue studies or careers in that field (Denner & Campe, 2018). Without opportunities to practise computing and digital making outside of the classroom, young people will not develop the same level of competence or expectations of success as their peers who have access to a computer at home and/or extracurricular activities, even if access within schools is becoming more equitable. Teachers suggest that young people with these sorts of access issues may be put off or feel out of their depth in classrooms with peers who sound very confident about their computing experience and expertise (Gretter et al., 2019), and this could have a negative effect on those from low-income backgrounds in particular.

Students' perceptions of CS as a discipline and a career may also affect their subject choices. Stereotypes about computer scientists being male, wearing glasses, and being 'nerdy' or 'geeky' are evident between 10 and 14 years old (Pantic et al., 2018; Denner et al., 2012). These narrow stereotypes can conflict with a young person's own sense of identity, or create a disconnect between the perception of someone who is competent with computers and someone who is a computer scientist (or between "doing computing and being a computer person"; Wong, 2017, p.299).

Stereotypes can also affect how interested students are in a subject or how relevant they see it to their future careers. In families who have little access to technology and limited understanding of CS as a discipline, young people are likely to have less exposure to a range of people involved in computing, and fewer opportunities to challenge stereotypes. This lack of family knowledge, skills and social connections (or resources, in Van Dijk's model) affects the career aspirations of young people for jobs in science more broadly (Archer et al., 2020) and may have a similar impact on computing career aspirations.

To understand young people's experiences of computing, it is necessary to speak with them directly. Those from low-income families may be less likely to be represented in research (Heinrich et al., 2010) due to a number of complex factors, but it is vital that their voices are heard to achieve equity in computing education. Very little research has been conducted on the experiences of young people from low-income families in computing, and the few studies that do exist tend to be based in the US. One study from the UK interviewed young people aged 13-19 who were attending a computing summer school, and asked them about their experiences of computing in and out of school (Wong, 2017). Despite being relatively interested in computing, as demonstrated by their attendance at the summer camp, they reported many of the narrow stereotypes of computer scientists outlined above, as well as a lack of aspiration towards computing careers.

The next section of this paper outlines a pilot study that we conducted with young people from low-income families to better understand their experiences of computing, focusing on those who had limited or no access to computing devices or the internet at home.

Figure 3. Some of the young people who received their computers as part of the Learn at Home campaign.

Speaking to young people about computing

At the Raspberry Pi Foundation, we recently set up a campaign to engage and support young people at risk of educational disadvantage due to the COVID-19 pandemic (the Learn at Home campaign[6]).

The scheme worked with a number of youth and community organisation partners to provide free computing equipment, internet connectivity, and digital support to young people who were unable to access their school work during school closures. A central part of this scheme was talking to the young people and their families about its impact on their ability to engage with their school work, as well as to communicate with teachers and peers. Some of the young people also agreed to participate in interviews for research purposes, and the study we undertook is described in more detail below (for the full study, please see Kunkeler & Leonard, 2021). We aimed to address the following research question: *How do young people from underserved communities feel about computing and their own digital skills?*

Method

Participants

The first wave of the Learn at Home campaign

[6] https://www.raspberrypi.org/blog/closing-the-digital-divide-with-raspberry-pi-computers/

Table 1. Demographic information for the thirteen interviewees.

Interviewee	Interviewee	Interviewee	Interviewee
1	13	Male	White British
2	13	Female	White British
3	16	Male	White British
4	11	Female	Asian
5	19	Male	White British/Carribean
6	9	Female	Black British
7	22	Female	White African/Carribean
8	13	Male	Black African
9	13	Female	Asian
10	15	Male	Black British
11	16	Male	White British
12	16	Female	White British
13	17	Male	White British

resulted in 947 young people receiving computers through a number of youth and community organisations. From each partner organisation, we shortlisted between two and five young people (24 in total) who had agreed to be contacted for research purposes and invited them to participate in an interview. Nine of those approached did not reply to the request, resulting in an initial sample of 15 interviewees.

The young people and their families who agreed to be contacted were sent an information sheet explaining the topics to be covered in the interview, how their data would be used, and their right to withdraw at any time without affecting any ongoing or future support from the organisation. After the interviews, one young person's data were excluded from analyses due to low language proficiency which made it difficult to understand the questions and respond. A further young person's data were excluded because the parent often interrupted and the data collected was therefore not reliable.

Demographic information for the thirteen interviewees in the final sample is presented in Table 1. The sample consisted of six females and seven males between the ages of 9 and 22.

Table 2. Themes and sub-themes identified in the interview analyses.

Theme	Sub-theme
'Mismatch between computing and own identities'	Underlying beliefs about 'computer people'
	Self-perception in computing
	Gender conventions in career aspirations
'Understated self-efficacy'	'Holding back'
	Barriers to computing

Around half of the interviewees identified as White British, and all belonged to underserved communities and therefore tended to be from lower socioeconomic backgrounds.

The interviews

Interviews lasted up to 30 minutes and were conducted via video or telephone call, depending on the young person's preference, and all participants under 18 were accompanied by a parent or youth worker from one of our partner organisations. The interviews focused on the young people's self-efficacy and feelings of belonging in computing, the type of people they thought of as 'computer people', and the value of computing for their future careers.

Interviews were conducted and transcribed before the researchers used thematic analysis to search for themes and patterns in the data (Kuckartz, 2014). First, the researchers read through the transcripts and, through an iterative process, agreed on a set of codes. These were then used to code the interviews, after which major themes were identified. The researchers met frequently to discuss the coding process and to agree on certain interpretations of the data.

Results and discussion

Two main themes were identified across the thirteen interviews, incorporating a number of sub-themes (see Table 2).

Mismatch between computing and own identities

When asked to describe a 'computer person', most of the young people stated that it could be anyone, for example:

"I don't think it's like a person with glasses and all that. I think I know loads of different people. I use computers now, do you know what I mean?" (i-11).

However, the majority also described someone who was highly intelligent, or someone who was nerdy or geeky:

"A bit smart. Very, very logical, because computers are very logical. Things like smart,

clever, intelligent, because computers are quite hard. Really skilled, maybe" (i-2).

"Intelligent, logistic, I wouldn't say nerd but. . . No, actually, yes, I would say nerd. Nothing bad about that" (i-1).

Alongside this perception, four of the young people (three of them female) associated a 'computer person' with being male:

"Oh, they're a boy, and they have loads of technology stuff in their house" (i-4).

The view expressed that anyone could be a 'computer person' was therefore often at odds with some more stereotypical ideas amongst the young people, perhaps suggesting a certain level of conflict between a more socially-acceptable view that anyone can achieve anything, and more deep-seated biases about computing as a discipline.

This conflict or mismatch continued to appear in the interviews as we asked about the young people's own abilities in computing and their future career aspirations. Although most of the participants reported that they could be a 'computer person', it was clear that this did not always fit with their interests or their future career choices:

"Well, I don't know. I'm more of a practical person" (i-11).

"I do use the computer, but I'm not an expert at it. And I feel like, with the computer, it relates to loads of online games. I don't normally play those [sic] kind of stuff. . . . Maybe, I don't know. I think I could change my opinion of computering [sic] a bit, but I don't think I would be a 'computer person', I guess" (i-4).

Only two participants wanted to pursue a career within computing, as developers in games and software, both of whom were white males. The female participants were more likely to choose roles in healthcare professions, although one did express an understanding of the value of computing for a future career as an architect: *"because if I want to make structures on computers, or 3D models, then I'm obviously going to use a computer, so I'm going to need computer science" (i-9).*

Overall, we found that none of the young people in the current study had a strong identity as a 'computer person', even those who chose CS at school or who were clearly digitally skilled. As in previous research (Wong, 2017), there seemed to be a distinction between doing computing, for instance in school, during leisure time, or for creative things, and being a 'computer person' who would continue to use computing in a future career.

Understated self-efficacy

The second main theme identified across the interviews was a sense of understated self-efficacy: although participants often reported quite a high level of technical competency and engagement with computing, they tended to understate their ability:

"compared to some of my teachers who don't know that Ctrl+C and Ctrl+V are a thing, I would say I'm pretty good. Maybe not a computer wizard that knows everything about what he's doing, but I know some things. I can do things" (i-1).

"We have done ICT from Year 7 all the way to Year 10. I think I know what I'm doing" (i-7).

This may be due to an attempt to gain social approval by appearing modest and underplaying their abilities (Luus & Watters, 2012) or perhaps it is a genuine underestimation of their knowledge and skills compared to an idealised version of a stereotypical computer scientist. Given that many of these young people only had access to computers for home use as a result of the Learn at Home campaign, they may also have been comparing themselves to the perceived competence and confidence of their classmates who did have access to computers and, therefore, more experience outside of school (e.g. Gretter et al., 2017).

Several barriers were mentioned to becoming a 'computer person', including the need for higher attainment in mathematics, needing to work hard, and needing to *"put my mind to it"*. Another young person explained that computing was just *"not [their] style"*, linking again to a perception of a computing identity that did not reflect their self-perception.

Together, the themes identified in our interviews support the limited previous research with young people from low-income families and provide evidence for the CAPE framework (Fletcher & Warner, 2020) and the Resources and Appropriation Theory (Van Dijk, 2005), highlighting the need to think beyond access to technology when considering the digital divide.

In closing

The theories and research presented in this chapter provide a complex picture of inequality in technology availability and use. This includes several aspects of computing education that contribute to the divide between those from lower- and higher-income families in terms of digital skills and opportunities for study.

Importantly, while access remains a significant factor in maintaining technological inequality, it is clear that providing access to devices and the internet is not enough to create a more equal society in terms of digital skills and participation. Greater efforts need to be made to improve the experience of computing education for young people from a wider range of backgrounds, highlighting the relevance of computing for future careers and breaking down stereotypes around computer science. Supporting families to better understand computing and to develop their own digital skills will also be vital, providing more social connections and role models in computing for young people. Finally, taking an intersectional perspective in both research and practice — considering a broad range of individual factors such as gender, family income, and ethnicity — must be the next step in understanding the digital divide and providing appropriate and relevant computing education.

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Should we be concerned about who is studying computing in schools?

Should we be concerned about who is studying computing in schools?

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Abstract

In the aftermath of national lockdowns, the need for digital competency has been made clearer than ever. However, millions of adults in the UK are said to lack digital skills, potentially causing many young people to miss out on the vast opportunities and career prospects afforded through a computing education. In this short chapter, we question whether we should be concerned about who is studying computing in schools. We begin with an overview of the numbers and social demographics of English students choosing Computer Science (CS) as a GCSE option. Of particular note is the underrepresentation of girls, who were amongst the least represented in CS compared to other GCSE subjects in 2020. We draw on various theories and explanations to explore possible reasons for unequal patterns of participation in CS. Our discussion includes changes to the English National Curriculum in 2014, experiences of self-efficacy, and the influence of family capital in parents and adult carers. We also draw upon social identity and science capital theories, and consider the lens of intersectionality to suggest how wider social inequalities and power dynamics can shape students' educational choices and trajectories. Finally, we suggest it is essential that we continue to explore social barriers to better understand how to widen participation among girls and diverse learners in computing.

Computing education in England: a brief overview

The development of technology and digital competency is widely considered as an important means for driving innovation and growth across the economy, especially since the start of the global coronavirus pandemic and associated national lockdowns (Learning & Work Institute, 2021). However, a digital crisis has been reported in the UK, where 5.4 million (or 10 % of) working adults are said to lack basic digital skills, and 4.3 million (or 8 % of) adults have no basic digital skills at all (Department for Education, 2019). The digital skills shortage persists in the labour market and has been considered a 'major risk' to business and economic development, with serious implications for society (Department for Business Innovation & Skills, 2016). It also suggests a disservice for millions of young people who may be disengaged from technology, and the vast opportunities and career prospects that can be afforded through a computing education.

Changes in the English National Curriculum from 2014 attempted to address the digital skills shortage by replacing Information Communication Technology (ICT) with a new subject, Computing (Gove, 2012). Computing places greater importance on computer science and programming, although reference is still made to computer applications, a core component of the old ICT specification, to develop safe and responsible use of technology (Brown et al., 2014). The introduction of Computing was accompanied by the creation of a new GCSE in CS, which has an increased emphasis on programming and has been positioned as a ‘rigorous, fascinating and intellectually challenging subject’ (Gove, 2012). Subsequently in September 2017, GCSE and A Level qualifications in ICT were discontinued.

Since 2014, the number of students choosing CS at GCSE has increased more than 4.5 times to just under 76,000 in 2020. However, this is still lower than the peak of the now defunct ICT GCSE, which had almost 97,000 exam entries in 2014. The number of students choosing CS at A Level has almost tripled. However, at both GCSE and A Level, the total numbers of young people choosing CS at GCSE and A Level still do not match those studying ICT in 2014. In 2020 alone, there were 25,000 fewer young people choosing any computing GCSE subject compared to 2014 (Joint Council for Qualifications (JCQ), 2020). The taught hours of computing for 11- to 18-year-olds, either for exam courses or general provision, decreased 41% between the introduction of the new curriculum in 2013 and 2020 (Kemp & Wong, 2021). Furthermore, the change in curriculum appears to have disproportionally affected some groups of young people more than others (Kemp et al., 2019).

Unequal patterns of participation

In many western countries, including England, most students engage with technology and there are few reported gender differences in terms of internet or social media usage (Office of Communications, 2015). However, in many English schools, there is a low uptake of girls in CS (Royal Society, 2017; Kemp et al., 2018). In 2020, only 22% of the 76,000 students who opted for CS at GCSE were girls. Additionally, whilst the gender gap has slightly narrowed over recent years, in 2020 there were still 27,000 fewer girls who sat any GCSE computing qualification than when the new computing curriculum was introduced in 2014 (JCQ, 2020).

Additionally, the pattern of uptake does not seem to be equally distributed between English schools. For example, girls in single sex schools have almost double the chance of sitting a GCSE in CS than those in a mixed sex school (7% vs 4%) – a pattern that is echoed in other subjects where girls are underrepresented, such as physics (Institute of Physics, 2018; Kemp et al., 2019). Students who have received pupil premium funding – that is, additional funding for children who are considered socioeconomically disadvantaged – are slightly less likely to choose CS, when in a school that offers it, than the overall student population: 23% vs 27%, respectively (Kemp et al., 2019). However, when gender and pupil premium are combined, the picture is slightly different, with 25% of girls and 21% of boys who received pupil premium funding in a school offering the subject sitting CS (Kemp et al., 2019). This pattern appears to be the case for all ethnic groups, with the exception of Chinese students, with those in receipt of pupil premium funding more likely to choose CS at GCSE.

However, a more complex picture emerges when looking at the Income Deprivation Affecting Children Index (IDACI) poverty indicator, a fine-grained scale that can be used to indicate levels of socioeconomic disadvantage in the area where a student lives. Amongst girls taking CS, socioeconomic disadvantage is positively correlated with uptake, with 7% of girls from lower socioeconomic backgrounds choosing CS versus 5% of girls from higher socioeconomic backgrounds. Interestingly, a different picture emerges for boys, where students from low socioeconomic backgrounds are less likely to study CS (21%), compared to students from high socioeconomic backgrounds (25%). The increased uptake of CS amongst girls from socioeconomically disadvantaged backgrounds (based on the IDACI poverty indicator) does not apply to Asian, Black, and Chinese girls. The trend of the most socioeconomically disadvantaged girls being more likely to take CS is heavily influenced by the larger numbers of White students in the population (Kemp et al., 2019).

Overall, the number of girls choosing CS remains low, and in the summer of 2020, consisted of only 22% of the GCSE cohort, dropping to 14% at A Level (JCQ, 2020). This low proportion of girls differs significantly from that of the previous ICT GCSE qualification, when in 2017, girls made up 43% of exam entries before the GCSE subject was discontinued.

Possible factors that influence unequal patterns of participation

Differences in student participation patterns in computing are clear, but the reasons behind them are complex. The consequences of these differences are serious for both the individuals and wider society, as computing is considered by the UK government as a subject which provides a 'strong foundation for further academic and vocational study, and for employment' (Department for Education, 2015, p. 10). Here, we discuss some of the possible factors that influence unequal patterns of participation with computing.

Curriculum

With the new GCSE CS curriculum introduced in 2014, students are developing greater skills in computational thinking that meet the demands of the economy, including coding, e-safety, networking and data storage (Larke, 2019; Williamson, 2017). As mentioned earlier, with the focus on digital knowledge, former (and often more popular) elements of the ICT qualification have been replaced with a greater focus on coding and programming as core components of the CS GCSE course. The emphasis on academic 'rigour' and 'intellectual challenge' within the subject may further dissuade young people whose self-concept is far removed from that of the idealised computer science student. Analysis of exam results position the CS qualification as one of the hardest GCSEs for students to achieve well at, while analysis of the ICT GCSE shows results in line with other courses. This calls into question the narrative that ICT was an easy course, at least at GCSE (Kemp et al, 2019; Kemp & Wong, 2021). There are therefore concerns that whilst the computing curriculum might help to increase numbers of future computer scientists, programmers or technology entrepreneurs, it may also exacerbate social inequalities by only appealing to students from particular demographics or with particular characteristics (especially boys), or to students with higher levels of access to computing resources, knowledges and contacts (Wong & Kemp, 2018). In addition to changes to the curriculum, there may be additional issues such as subject timetabling in schools and computing teacher recruitment, development and retention. Students' GCSE and A Level choices are largely influenced by the hours and options made available to them, especially given the nature of post-sixteen entry requirements, where CS may be regarded as less desirable, useful or necessary compared to other subjects that are timetabled to run concurrently (Abrahams, 2018).

Self-efficacy

Differences in self-efficacy can influence the ways in which students identify and participate in computing. Self-efficacy is a self-belief which can be shaped by a number of individual and social factors (Bandura, 1999; as elaborated elsewhere, see SCARI Computing, 2021). For example, students' self-evaluations of past performances when undertaking a task in computing (e.g., writing lines of code) are likely to determine their attitude towards undertaking the task again in the future. Similarly, self-efficacy may be influenced by observations of peers and perceptions of peer success. If a learner observes their classmates undertaking a task successfully, they might believe that they also stand a chance of completing the task (i.e. 'if they can do it, so can I'). A learner may also be influenced by 'social persuasion' from peers, teachers or parents, or 'emotional responses' to a task or event (e.g., sitting a computing exam), which may reduce levels of self-efficacy due to high levels of anxiety around its outcome.

In the context of secondary education, self-efficacy in computing might predict a young person's choice to study computing. While this area of education currently remains underexplored, girls' perceptions of computing and mathematical self-efficacy have been said to correlate with their participation in CS (Lips & Temple, 1990). Overall, girls seem to achieve slightly lower exam results in CS (and STEM) than their other subjects, especially subjects such as English, where relative performance in CS has been found to be most acute when controlling for average attainment scores (Kemp et al., 2019; Kemp & Wong, 2021). This would assume that all learners work just as hard in school, but disparities in outcomes between subjects suggest girls may contribute to lower feelings of self-efficacy in CS. Similarly, a substantial number of studies have demonstrated gender differences in self-efficacy relative to computing, especially those that involve advanced computing skills (Cassidy & Eachus, 2002; Huang, 2013; Torkzadeh & Koufteros, 1994).

Family capital in parents/adult carers

Furthermore, there is a strong but complex link between a child's relationships with their adult carers (including parents, extended family and their teachers) and whether a young person chooses to study STEM subjects (e.g. Archer et al., 2012; Jones & Hamer, in press). There is now considerable evidence that parents' or carers' own views in relation to subject choice and career options have important outcomes for their children. For example, Jacobs et al. (2006) demonstrated that parents' gendered attitudes towards the occupation expectations of their child at the age of 15, are closely linked to their child's own aspirations at the age of 17. Not only that, but parents' gendered expectations of jobs for their child at the age of 17 were found to be related to the actual job the child had at 28. If a parent or teacher has a greater interest in computing and minimally gendered views, it would perhaps be unsurprising that they would be more likely to consider computing as an option for the young people in their care. Therefore, values and expectations shared by parents, relatives and/or teachers, through discussions at home or in school, may shape a young person's aspirations and perceptions of computing as a viable option for themselves (e.g. Wong, 2017). It would then seem possible that a teacher, family member or peer may also positively reinforce beliefs that a young person has by telling them that they believe they can complete a computing task (or 'become' a computing person) (SCARI Computing, 2021).

Social identity and science capital

Students as individuals bring with them a unique array of skills, perceptions and experiences which can shape their attitudes and performances in different subjects. Students may have different levels of access to computing resources, knowledge and contacts. There may also be different cultural expectations of success and financial security, and opportunities can vary across subjects. In the context of STEM, these factors can either increase or lower a young person's *science capital*, and may influence their decision to study STEM subjects (Archer et al., 2015; Bourdieu, 1977; Moote et al., 2020; Wong, 2012). In other words, if a learner has a high science capital, they are more likely to opt for science-related subjects, so we might suggest that if students have a high *computing capital*, they are more likely to opt for a computing education and aspire for a computing-based career.

However, notions of identity are complex and shaped by social constructions such as gender, ethnicity and social class. Unequal patterns of participation in CS may unfortunately be a product of powerful perceptions of what is considered 'normal' or 'appropriate' for students depending on their social demographics, identity expressions or locations (e.g. where they live, go to school, etc.). These factors are said to influence students' educational choices and trajectories (Archer et al., 2010; Bourdieu & Passeron, 1977). Research suggests that even when young people report enjoying STEM subjects, finding them 'fun', 'exciting', 'important' or 'interesting', they may still consider them as 'not for me' (Archer et al., 2010; Jenkins & Nelson, 2005). Young people's interest and engagement with STEM, which includes computing, are therefore likely to be shaped by their social positionings, and the specific gendered, racialised and classed identity constructions that are considered socially desirable.

Indeed, some constructions of a 'computing' identity may be ruled out as socially *undesirable*. Stereotypes such as 'geeks', 'nerds' and 'hackers' are gendered as typically masculine (e.g. 'antisocial' and 'technical') (Varma, 2007), racialised as white (Mendick & Francis, 2012), and reaffirmed by mainstream discourses, movies and media portrayals of computing enthusiasts and specialists (e.g. representations of scientists on *The Big Bang Theory*) (Wong, 2017). Depictions of white, privately educated, male leaders of tech giants, like Bill Gates, Steve Jobs, Elon Musk and Mark Zuckerberg, are frequently used to inspire students in computing in the forms of pictures, quotations or wall displays. While this might work for some students, it highlights the lack of known role models who identify differently to the stereotypical white, privately educated man, potentially reinforcing damaging ideologies that the latter is better suited for careers in computer science and technology, and that business and commercial outcomes are the end result of the study of computing (Wong & Kemp, 2018).

In other words, girls can certainly 'do' computing, but may struggle to aspire to a computing education because they do not 'fit the label' of what constitutes a 'typical' computing person (Archer et al., 2010; Wong, 2017). This suggests social inequalities can deter girls and minorities from identifying with and participating in a computing education. Alternatively, they may seek more desirable identity expressions through participation in other subjects (Archer et al., 2010). National statistics indicate that girls were most represented in subjects such as Health and Social Care, and Art and Design, and least represented in CS (JCQ, 2020). Yet, the experiences, representations and performances of gender minority learners remain underexplored. Mindful of these social inequalities, science capital is likely to vary among students depending on their resources and knowledge, and may help to explain the underrepresentation of girls, especially from diverse backgrounds, in computing.

Intersectionality

Another way to interpret unequal patterns of participation in CS may be through the lens of intersectionality (Crenshaw, 1989), which identifies intersecting modes of inequality that occur on the basis of sex, gender, race, ethnicity, sexuality, disability, neurodivergence, and so on. Intersectionality allows for a deeper understanding of the different ways students might experience social inequalities, and how systems of power can discriminate against multiple characteristics and social demographics at any one time. Therefore, students who are not represented by the majority – whether in terms of gender, ethnicity, or any other dimension of social identity – may experience multiple, intersecting inequalities or barriers, such as sexism, gender discrimination, and racism, that are likely to shape their educational choices and trajectories.

For example, the social stereotypes described in the previous section may transpire to (un)conscious biases (and vice versa), which may exacerbate social inequalities further. There is evidence to suggest that gender differences exist in teacher-student interactions in physics classrooms, where boys have been found in some schools to dominate classroom interactions, either by calling out or volunteering answers more often than their peers (Institute of Physics, 2016). There may also be additional factors that shape social assumptions about who has the knowledge capacity or cultural competence to complete certain tasks. The perception that a student must be 'really smart' to do CS seems to persist among both students and staff (Margolis et al., 2017). Yet, there seems to be little criticality about the subjectivity of intelligence and how it is measured in the context of computing. This is important when we consider whose knowledge counts and why, and the types of knowledges and skills that are valued over others (Schucan Bird et al., 2020). If diverse learners feel underrepresented, unheard or undervalued in the computing classroom, they may experience a lower sense of self-concept or belonging, which has been said to impact student engagement, attainment and retention (Gandolfi, 2021). Intersectionality is therefore a useful theoretical tool for understanding students' unique experiences of social inequalities, and how they may play out in the computing classroom to cause unequal patterns of participation.

What next?

The evident lack of girls and certain minorities choosing computing-related subjects at both GCSE and A Level should be of concern to us all, as it likely reflects an inequality that will have reverberations in the workplace and wider society for years to come. If patterns of uptake for GCSE CS persist and computing continues to be side-lined in English school timetables, a significant proportion of a generation of young people will continue to miss out on the enjoyment and opportunity that computing has to offer. The reasons for the decline in girls in computing education are myriad and complex, but it is essential that we continue to explore the barriers faced by young people in schools and wider society. By understanding the reasons for unequal participation, we may learn how to better keep the door open to the world of opportunities that are afforded through a computing education.

About the SCARI Computing project

The SCARI Computing project aims to explore the factors that explain the participation and performance of girls in English secondary school computing with a particular focus on CS exams. The study will use the National Pupil Dataset and School Workforce Census, alongside school case studies through quantitative and qualitative data collected from school managers, students, and documents, such as schemes of work and wall displays. We will be working with schools with a high uptake in GCSE CS to understand the views of their students and staff, through student surveys, staff interviews, and to learn from their computing curriculums. We hope this will inform our current understanding of girls' participation in computer science, as well as impact policies and educational interventions to reduce the participation and attainment gaps between diverse students in computing education.

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Visit www.nuffieldfoundation.org

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Equity principles for including learners with disabilities in K-12 CS education.

Equity principles for including learners with disabilities in K-12 CS education

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Abstract

To truly consider equity and inclusion in K-12 computer science (CS) education, we must take active steps to include all learners, including those with disabilities. Although teachers are committed to supporting all learners in CS education, they often report that they lack the pedagogical strategies to adequately meet the needs of all these learners. This chapter has two aims. First, it highlights what we currently know about the inclusion of students with disabilities in K-12 CS education from an equity perspective. Second, this chapter also frames Universal Design for Learning (UDL) as an approach that can be used to more meaningfully include all learners in CS education by highlighting instructional strategies that result in increased participation, learning, and belonging of students with disabilities in K-12 CS education.

Introduction

Although there has been growing attention to equity and inclusion of all learners in K-12 computer science (CS) education, this attention has often not included the participation of learners with disabilities. This lack of attention has resulted in both a limited understanding of the extent to which students with disabilities are included in CS education as well as lack of pedagogical approaches that teachers can use to include students with disabilities in their CS instruction. The purpose of this chapter, therefore, is to outline four equity principles that can guide the discourse about the participation of students with disabilities in K-12 CS education.

CS equity principles

Equity principle 1: Learner variability is the norm and is an asset in the CS education classroom

When looking into most K-12 classrooms, it quickly becomes clear that learner variability is the rule, not the exception (Pape, 2018, Rose, 2016). Students have a range of expertise, background knowledge, languages, strengths, and challenges. Additionally, this variability is not static; strengths in one area do not predict strengths in other areas. For example, some learners will have strong visual spatial abilities but struggle with planning projects that require multiple steps. Other students will have experience with coding open-ended computational artifacts but when asked to apply those skills within the context of a CS plus math lesson, they may struggle with generalizing these skills because of limited understanding of the mathematical concepts integrated within the CS lesson. Thus, we all have a jagged learning profile; strengths in one area do not necessitate strengths in others (Rose, 2016). Thus, CS teachers work in classrooms that are diverse, so designing learning experiences for the average learner makes little sense.

When considering the participation of students with disabilities within this context, we normalize disability as part of the human condition. It is simply part of the variability that exists in society. In the United States, for example, according to the National Center for Education Statistics (2021), there are currently approximately 7.3 million children receiving special education services due to a disability (Irwin et al., 2021). Additionally, disability should be considered part of the human condition rather than something different or outside of the "normal" experience. In fact, the World Health Organization (2002) situated disability as part of typical human functioning. Similarly, the Individuals with Disability Education Act (IDEA, 2004), which is the legislation in the United States that guides services for students with disabilities, begins with the statement, "Disability is a natural part of the human experience and in no way diminishes the right of individuals to participate in or contribute to society." It is important to note that, like all people, this group of learners is not homogeneous, and they bring unique lived experiences, knowledge, and perspectives into their learning environment. Additionally, the majority of these learners are taught alongside their peers in general education settings, so teachers should assume that their CS classroom will include learners with disabilities. When we acknowledge learner variability from this perspective as well as this data, it no longer becomes acceptable to design instructional experiences that are "one size fits all". Instead, instruction should be designed and flexible enough to include all learners.

Equity principle 2: All learners, including those with disabilities, deserve to be included in K-12 CS education

For meaningful participation of all learners to occur, we must challenge our assumptions about who belongs in CS. Making the stand that all learners, including those with disabilities, deserve the opportunity to be included in CS education is a critical step towards access and equity in CS education (Ladner & Israel, 2016). When this shift takes place, teachers realize that students with disabilities are an integral part of their classrooms. This shift also showcases the strengths of learners with disabilities as their participation finally is acknowledged as meaningful and impactful on the classroom community, thus countering the deficit perspective often associated with learners with disabilities.

Who has access to CS becomes complicated when examining access by disability categorization. In fact, it is difficult to know the extent to which students with disabilities are included in K-12 CS education due to issues such as confidentiality, how disability is classified, and permission to ask for sensitive information such as disability status in educational research (Blaser & Ladner, 2020). A recent study in New York City Public Schools showcased the complexity of studying the participation of students with disabilities in CS education, as students with some disabilities were included to a greater or lesser extent than students with other disabilities. In this study, Fancseli and Israel (2021) concluded that, when examining the data in aggregate, students with disabilities were included in CS education at a rate similar to students without disabilities. However, when examining that data by students' disability categorization and grade level, students with certain disabilities were included at lower and higher rates than their peers and students with other disabilities. For example, although 9.5 % of high school learners in New York City Public Schools take CS coursework, only 6% of students with learning disabilities do so, but 12.6% of students with Autism take high school CS. This phenomenon can be explained by other research suggesting that teachers' views towards inclusion of students with disabilities often relate to teachers' views of who has the necessary

Table 1. Barriers to inclusion of learners with disabilities in K-12 CS education.

Barriers to inclusion	**Examples**
Systemic barriers	- Inaccessible CS curricula, tools, and materials developed and adopted widely - Biases of decision makers about who belongs in CS
School-level barriers	- Scheduling priorities wherein students must leave CS instruction to receive specialized instruction (e.g., reading support, speech therapy) - Lack of CS professional development aimed at special education teachers and instructional aides - Lack of professional development in inclusive practices aimed at CS teachers - Lack of available assistive technologies for students to use alongside CS tools - Lack of accessible curricula, tools, and materials
Classroom-level barriers	- Biases about the abilities and motivations of some learners - Teachers' limited knowledge of inclusive pedagogical practices - Over- or under-supporting students based on assumptions of competence (or lack of competence) rather than on data

abilities and dispositions to succeed in the CS classroom (Israel et al., under review). These studies point towards the need to (a) examine participation in CS in a more in-depth way, and (b) not lump all students with disabilities into a single category. Thus, the belief that all students should have access to CS manifests both initiatives that examine participation data in order to address any participation gaps as well as beliefs and actions of individual teachers that promote participation and inclusion.

Equity principle 3: Understanding barriers and pathways to inclusion and access in CS education is critical

Inclusive CS education that meaningfully includes learners with disabilities cannot occur without a thorough examination of both the barriers and pathways to participation. This examination must focus not only on whether students with disabilities are enrolled in CS education, because simply placing children in a CS classroom does not guarantee that they will have meaningful educational experiences (Israel et al., 2020 under review). Thus, we must use an ecological systems approach that examines barriers and pathways in the classrooms, schools, and broader systems that influence decisions about participation. Table 1 provides some barriers at different levels along with examples of such barriers.

The barriers in Table 1 are not simple; consequently, solutions might require a great deal of coordination and effort. When we begin

Table 2. Pathways to inclusion of students with disabilities in K-12 CS education.

Pathways to inclusion	**Examples**
Systemic barriers	- Wide-scale expectation for the development of accessible CS curricula, tools, and materials - Advocacy by decision makers about CS for all learners across school environments - Inclusion of disability as part of the inclusive CS education discourse
School-level pathways	- Availability of CS education to all students, across instructional settings - Scheduling that allows students to attend both CS instruction as well as specialized instruction - Time allocated for co-planning between CS educators and specialized instructors such as special education teachers and English as a Second Language (ESL) educators - Institutionalization of co-teaching in CS classrooms to ensure necessary individualization as needed - Access to assistive technologies in CS classrooms
Classroom-level pathways	- Teachers' commitment to meaningful participation of students with disabilities in CS education - Teachers' use of inclusive pedagogical approaches such as Universal Design for Learning - Classroom-level advocacy for the participation of all learners in CS education (advocating for students to not be removed from CS instruction)

to unpack and understand these barriers, we can start considering ways of addressing them and creating pathways to inclusion. For example, if a school recognizes that many students do not attend CS instruction because specialized instruction is scheduled for the same time, school administrators, teachers, and other service providers can work together to address this scheduling challenge. Specialized instruction (e.g., intensive reading intervention) can take place at a different time. Alternatively, specialists can work within the CS instructional context. For example, the speech therapist might reinforce communication skills during CS instructional time. Table 2 provides some common pathways and examples.

Equity principle 4: Proactively designing instruction to account for the range of learners is key to successful inclusion

In addition to challenging common assumptions about who belongs in CS education and understanding barriers and pathways, it is critical to use pedagogical practices focused on inclusion and accessibility. One such approach is the Universal Design for Learning (UDL) framework, which is a proactive approach to

Table 3. UDL principles and applications in K-12 CS education.
Note. Adapted from Israel, M., Lash, T., Ray, M. (2017).

UDL principle	Explanation	Examples in CS education
Multiple means of engagement	Learners come into classrooms with different motivations and different ways that they engage in content. Thus, providing different ways of engaging learners is critical.	- Provide choice in student projects - Provide supports and extensions in projects - Model perseverance and problem solving - Break up coding activities with opportunities for reflection such as "turn and talks" with peers
Multiple means of representation	Learners differ in how they prefer to acquire and process information. Thus, having a range of representations is critical.	- Provide access to video tutorials of computing tasks - Select coding apps and websites that allow students to adjust visual settings (e.g., font size, contrast) - Provide graphic organizers and anchor charts with reference to blocks or relevant syntax
Multiple means of action and expression	Learners differ in how they best demonstrate and express their understanding. Thus, providing options for how students demonstrate their learning is critical.	- Include unplugged activities that demonstrate the physical relationship of computing concepts - Provide multiple entry points into computational projects - Guide students to set goals for long-term computational projects

planning instruction that reduces barriers to learning and empowers all learners to become expert learners (Hitchcock et al., 2002). This framework assumes that there is no single instructional approach that is optimal for all learners in all contexts. Thus, we must build flexibility into our instruction, tools, and materials so that we can reach all learners. UDL has three major principles that provide guidance in how to consider instructional flexibility. Within each of the three principles, there are guidelines and checkpoints that provide the details of how to enact those principles. The UDL principles can be applied within all aspects of instruction, including the curriculum that is chosen as well as how it is enacted (Burgstahler, 2009; Burgstahler, 2011). Table 3 provides a summary of these principles and guidelines alongside examples for CS education. An example of a UDL-based instructional activity involves developing a "multiple entry point" activity wherein students have options between like-activities that have differences in the level of scaffolding provided. Teachers can, thus, provide options wherein students choose between computational tasks that include:

- Playing and remixing a Scratch project that has already been constructed.
- Debugging a program that has errors using the same "play and remix" project.
- Constructing from a "exploded" code project wherein students reconstruct code that has been deconstructed using the same "play and remix" project.
- Extending beyond the original project with additional tasks and steps. Students are not told which option to pick but can toggle between projects, and all participants meet learning objectives, and are meaningfully included in the classroom activity.

Illustrative example from the field: BrowardCODES-for-All project

The BrowardCODES-for-All project was a collaboration between BrowardCODES, the computer science education initiative in Broward County Public Schools[7] and the Creative Technology Research Lab at the University of Florida[8]. It focused on professional development (PD) aimed at special education teachers in Broward County Public Schools to encourage them to integrate CS into their instruction in a way that meaningfully meets the needs of their learners. This PD included topics such as how to integrate UDL into CS education, individualizing CS instruction for students who had more significant needs, Florida CS standards, cross-curricular connections (e.g., literacy and math instruction), exploration of accessibility features within CS software and hardware, and a lot of time for play and exploration. Additionally, time was reserved to discuss ways of overcoming challenges that the teachers experienced. Challenges ranged across three main areas:

1. Access to tools and resources: Through grant funding, teachers were given tools such as Wonder Workshop Dash and Sphero robots, extensions such as the Wonder Workshop Puzzlets pack for Dash robot. However, they did not receive whole-class sets. This limited set of tools resulted in challenges when the teachers wanted to implement whole-class instruction using these devices. Discussions related to overcoming these barriers primarily focused on ways of organizing center-based learning stations, bringing in more unplugged activities, and utilizing pair programming so that two learners can share a device.

2. Accessibility challenges: Teachers described the need to support students with low vision or mobility issues. A considerable amount of time was spent exploring features within the tools themselves (e.g. the capability of the Sphero robots to be navigated using voice and swiping commands). We also had discussions about adding Braille to the Puzzlets tool so that students with low vision could utilize that tool to program the Dash robot to move rather than using touch-screen devices, which were not accessible to students who are blind or have low vision.

3. Instructional approach challenges: Other challenges that the teachers described focused on which instructional strategies would engage learners best. The teachers reported that their students were often frustrated when their code did not work as intended or, during pair programming, the navigator was not as engaged as the driver. These sets of challenges were discussed as opportunities to introduce UDL-based instructional approaches such as teaching effective collaboration strategies with consistent feedback, clear goal setting, and acknowledging and celebrating persistence and learning through failure.

Through this PD, the special education teachers created lesson plans that they implemented in their classrooms. They used a combination of

[7] https://www.browardschools.com/Page/35959
[8] https://ctrl.education.ufl.edu/

UDL-based approaches alongside individualized support so that all their learners could engage meaningfully in CS education.

Conclusion

The inclusion of students with disabilities in CS education is just emerging in the CS education discourse. The limited research that does exist points to the promise of approaches such as UDL (Israel et al., 2020), but also points to the need to provide teachers with professional development and other support so that they can best meet the needs of all their learners (Israel et al., 2018). Many additional research questions remain about how to best serve this population of learners. Fancseli and Israel (2021) outlined some of these major questions that included: To what extent is participation of students with disabilities influenced by attitudes and perceptions about who belongs in CS? And given the intersectional nature of disability with other factors, what is the relationship between CS participation, disability status and other demographic factors such as race/ethnicity, socioeconomic status, and gender? Other questions remain about the relationship between inclusive educational practices and the learning outcomes of all learners, including those with disabilities.

Additional resources

- The UDL Principles can be found at CAST: https://udlguidelines.cast.org/
- Application of UDL in K-12 CS education can be found at the Creative Technology Research Lab at the University of Florida website: https://ctrl.education.ufl.edu/wp-content/uploads/sites/5/2020/05/Copy-of-UDL-and-CS_CT-remix.pdf
- Further resources about access and inclusion in CS education can be found at the AccessCSforAll Center at the University of Washington: https://www.washington.edu/accesscomputing/accesscsforall

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Computing for generative justice: decolonizing the circular economy.

Computing for generative justice: decolonizing the circular economy

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We are often told, quite rightly, that the only hope for a sustainable future is to transition to an economy that is circular. We envision discarded products recycled, carbon exhaust reutilized, waste heat warming houses, and so on: the “industrial symbiosis” touted by corporate giants and government research agencies. But these formulations often fail to address the underlying problem. There is no reason to think that more environmentally sustainable technologies will avoid the low paid work and poverty the current technology creates. Current trends in neuromarketing, spyware, gamification and related technologies are dedicated to increasing consumption of things we do not need. Microplastics--which are emitted just as much by recycling as any other plastic process--are now found in the placentas of unborn babies. We are seeing an increase in “voluntary segregation” created by real estate costs, patrolled by militarized law enforcement and fueling a rising tide of racialized nationalism. But this need not be the case. A decolonial or *generative* economy could bring the circular flow to all forms of value exchange: to ecological value; to labor value; and to social value. Enabling the next generation to view STEM through this lens, and effect this transition, requires a different approach to knowledge; and a shift in the kinds of computational tools we provide.

Some forms of knowledge are purely social, subjective and personal. What I think is the best tasting food is not necessarily what you think. Other forms are more objective: if I add in a bit of coloring to oil, water and alcohol, and pour them into a glass cylinder, they will eventually settle into their respective density layers. No human has to be present; they will sort themselves on their own, surely a good sign of objective facts. But knowledge *systems* are far more complex than isolated facts, and involve the combination of social and objective understandings. Consider, for example, the history of Euler’s formula for polyhedra (figure 1). We know it to be Vertices - Edges + Faces = 2. But it is actually a history of counter-examples. Hessel pointed out that a hollow inside a cube is an exception; Möbius did the same for two pyramids joined at a vertex. Each time the math community had a

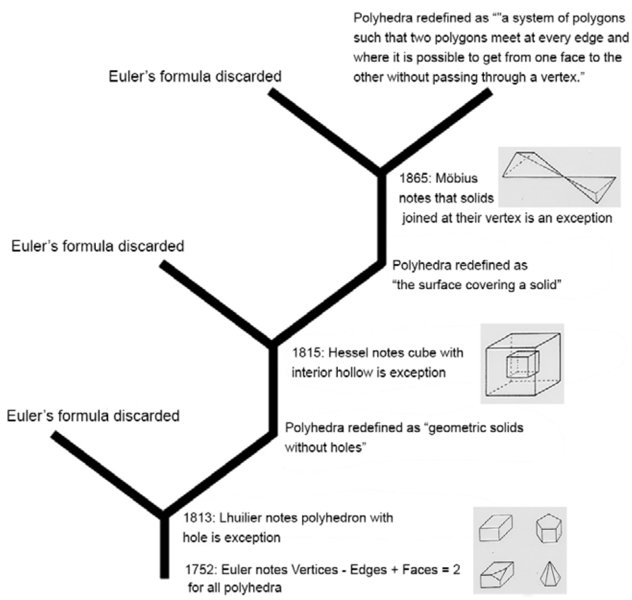
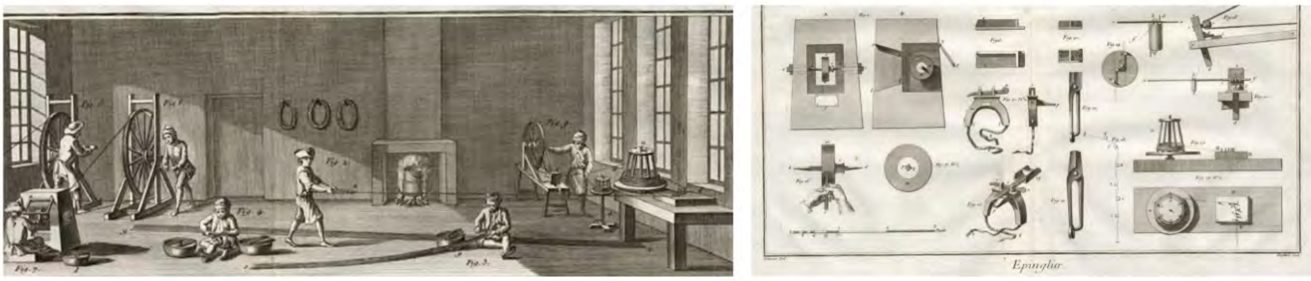


Figure 1. The evolution of Euler’s formula for polyhedra, with controversies and branch points.

Europe: Extractive Economy and Extractive STEM Co-Evolve



Economics	Science and Technology
Skilled employees demand high pay. Break into little tasks: "deskilling"	Physics: Efficiency metaphor defines relation of energy to work: extracting maximum work for minimum effort.
Borrows term "efficiency" from physics: deskilling is just following Nature's laws	Engineering: defines tool design driven by Smith's deskilling goals
Competition in technology requires business advances in accounting and logistics for extraction	Computing: Charles Babbage cites Adam Smith's pin factory as model for computer

Figure 2. The co-evolution of Europe's labor extraction and its STEM foundations.
Illustration: Designed by Goussier, engraved by Defehrt (1762); file author unknown, Public domain, via Wikimedia Commons.

debate. Each debate is a potential *branch point* in the evolution of Euler's formula; a path to mathematics we do not have, but could just as easily have adopted. It became a positive feedback loop: the more it was defended, the harder it became to dislodge it, even though the definitions had to become increasingly baroque. Perhaps some day we will encounter aliens and see the math resulting from a different branch point.

But we don't need to venture into space for that; we have different knowledge systems right here in earth's cultural traditions. They too have branch points at which they began to differ. Europe's early knowledge systems were strongly influenced by Greek, Roman and other empires. A positive feedback loop between wealth extraction, technology development, and military power set Europe on a trajectory as surely as did the feedback loop for Euler's defense. Industrialization in the modern era amplified this tendency. Figure 2 shows how the kinds of deskilling of labor celebrated in Adam Smith's

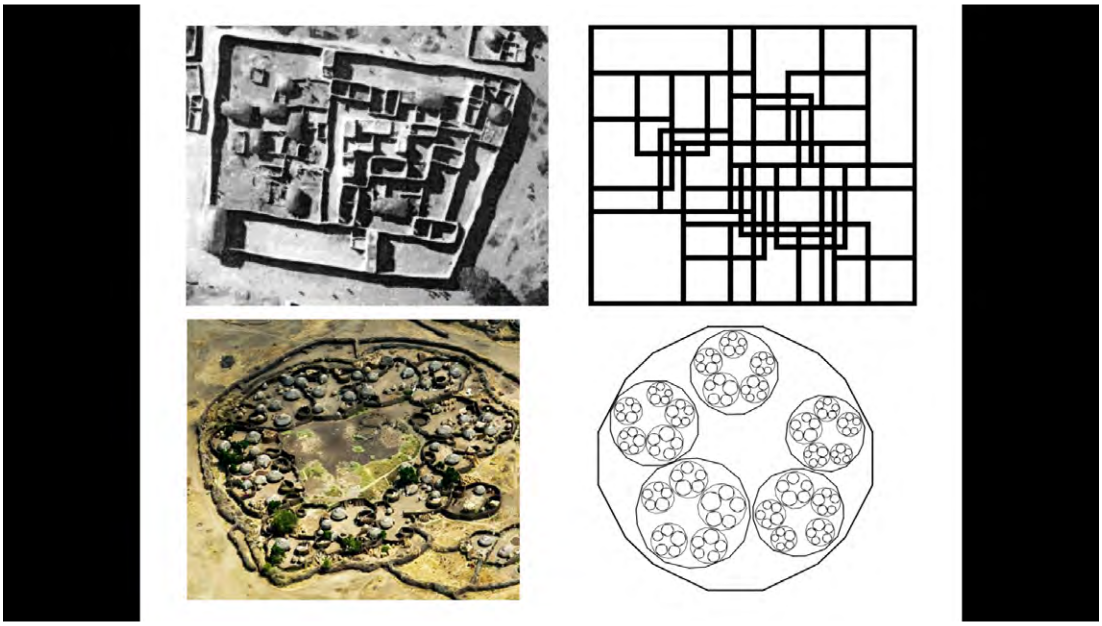


Figure 3. Fractal architecture in Africa.

Wealth of Nations stimulated the development of technology for this purpose. Conversely, when physicists used the term "efficiency" to define maximum work for minimum effort, it was embraced by the business world (Smith in particular declared that in a static economy, workers should be paid wages that keep them on the edge of starvation, since no population growth is required until more factories need to be filled). Charles Babbage specifically cites Smith in his description of the first computer: the deskilling of human labor was the perfect model for separating functions like memory, math and output. Conversely, Babbage envisioned computers as the ultimate technology for replacing high wage artisans with low paid, deskilled drudge labor. While factories focused on labor value extraction, farms, fisheries and the like developed STEM for ecological value extraction, degrading soil, air and water. Deforestation and deskilling might seem like different processes--one devastating to nature, the other to culture--but they are ultimately the result of the same knowledge system: extractive STEM.

Indigenous knowledge systems took a different branch point, that of generative STEM. In nature, value is generated in cycles: biomolecules like the Krebs cycle; organisms like the reproductive cycle; entire environments in the ecosystem cycles. Indigenous cultures utilized these circular flows, in many cases enhancing nature's productivity rather than harming it. Far from the colonial view of ignorant "children of the forest", Indigenous knowledge reflected sophisticated understandings and techniques for maintaining circular flows of value, without extraction. Because it has a radically different basis, it is hard to recognize Indigenous STEM when we see it.

Figure 3 shows some examples of fractal architectures in Africa. They are not created by a single master-mind imposing their structure on the masses; the top-down model celebrated in works such as Ayn Rand's "Atlas Shrugged" or the USSR's Stalinist urban planning. Rather, they evolve bottom-up, growing in adaptive response to local needs: goals that Western

Figure 4. Top: the roof of a church in Ethiopia; its nonlinear staircase; an African symbol for recursion. Bottom: fractal simulation for an Ethiopian cross; the cross in metal and cloth.

architectural sciences have barely conceived. Africa's recursive fractal forms can be found in textiles, sculpture, and myriad symbolic forms; in practical crafts from windscreens to winnowing baskets; and in the structural flows of restorative justice, ecological sustainability and egalitarian relationships traditional to these cultures (figure 4). Space does not permit more detail here, but more can be found in Eglash (1999) and my TED talk.

Africans could not bring their physical artifacts across the middle passage, but cornrow hairstyles were one of the fractal traditions that survived and flourished. Figure 5 shows one of our efforts to "translate" those recursive traditions into contemporary STEM education practices in the US. The process is similar when we work with Native American, Latinx, and low income groups of all ethnicities. We begin by interviewing artisans, elders, anyone who represents that traditional approach, both to make sure we have permission, and to ensure we are representing the tradition respectfully and accurately. We then translate their concepts into a set of online apps called Culturally Situated Design Tools, or CSDT for short (csdt.org). Students use those tools to learn what we call "heritage algorithms" (Bennett 2016). At first they are simply simulating the originals. They then use them creatively to generate their own innovations. The next step is to facilitate physical rendering of the designs, using laser cutters and other digital fabrication. This creates two opportunities.

First, it opens the involvement of adult artisans. In the case of figure 5, it inspired local braiding shop owners to get involved. They suggested a focus on the pH damage in commercial hair

Figure 5. The generative cycle using a cornrows simulation tool at csdt.org.

products, so that became a new CSDT. It also inspired new entrepreneurial activity, with one student producing and marketing her own organic, pH neutral hair product. And that is the second opportunity: offering the chance to create healthier, more sustainable and more just versions of STEM. In Ghana this generative cycle showed statistically significant improvement for students in controlled comparisons to their current approach (Babbitt et al., 2015). But we also created new opportunities for STEM activities, such as solar production of Ghanaian fabric dye, mushroom foam replacement for plastics, and intergenerational collaborations between youth using laser cutters and elders with sewing machines[9] In our most recent project, we developed AI that can distinguish between factory fakes and hand-made fabrics (Robinson et al 2020). Machine learning of this sort is not limited to the microscale; by networking these small artisanal operations into larger cooperatives (our example[10]) and those into macroscale ecosystems, one can imagine a more just, sustainable and equitable role for STEM in sustaining an entire artisanal economy (Eglash et al 2019).

Conclusion

These generative STEM examples all utilize the Indigenous circular structure: starting with local knowledge; translating that into STEM equivalents; facilitating their creative use both virtually and as physical renderings; and bringing that value back to the community. They range from US inner city applications, to Native American, Latin American, and African communities (Eglash et al 2020). At this point they are merely “proof of concept”, but I hope they offer a vision for the kinds of change that need to occur.

[9] https://generativejustice.org/projects/
[10] https://africanfuturist.org/

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Addendum

Alongside the seminar series, the Raspberry Pi Foundation led a project on culturally relevant pedagogy and culturally responsive teaching, which is described in the following pages.

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Localising culturally responsive computing teaching to an English context: developing teacher guidelines.

Localising culturally responsive computing teaching to an English context: developing teacher guidelines

Hayley C. Leonard, Sue Sentance, and Diana Kirby (Raspberry Pi Computing Education Research Centre, University of Cambridge, UK)
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Abstract

This short report provides an overview of a project we undertook at the Raspberry Pi Foundation to develop a set of guidelines for computing teachers on culturally relevant and responsive computing teaching for an English context. We first provide an overview of the context and literature in the field, before describing the process of developing the guidelines with our working group. We then outline the next stages of development for this work.

Introduction

In England, there is a National Curriculum which ensures that all children have mandatory computing lessons between the ages of 5 and 16. Between 14 and 18, students can elect to take formal qualifications in computer science (CS). Despite all children having access to computing in school from an early age, those choosing to continue with formal qualifications in CS are mainly white and Chinese males, with other ethnic groups and females underrepresented (Kemp et al., 2018). This is similar to patterns of participation in K-12 Computer Science in the United States (US; Gallup, 2020), where access to computing education is not mandatory and differs between states and local districts.

A lack of cultural relevance and responsiveness in the computing curriculum could contribute to the underrepresentation of young people from some minority ethnic backgrounds in formal computing qualifications in England, affecting the way that these young people engage with and learn the subject. Although the English population is majority White, there is a great deal of regional variation (Office for National Statistics, 2011). Ensuring that the curriculum is responsive to the diversity in the local community is therefore of great importance. This requires not only adapting the curriculum, teaching methods and materials to engage a broader range of students, but also developing teachers' understanding of the biases in current practices and helping them to work towards more equitable approaches to teaching computing (Goode et al., 2020a, 2020b). The next sections identify some of the theoretical frameworks and research that form the basis of attempts to address these issues.

Theoretical frameworks

Cultural relevance and responsiveness in education are the focus of several key theoretical frameworks that have emerged in the US since the 1990s. Culturally Relevant Pedagogy (Ladson-Billings, 1995), Culturally Responsive Teaching (Gay, 2000), and Culturally Sustaining Pedagogy (Paris, 2012) all focus on the importance of allowing students from a range of backgrounds to express their cultures and identities through learning activities that are meaningful to them and that allow them to excel academically. They move away from "deficit thinking" (Yosso, 2005, p.75) in relation to students from minority groups, aiming to address the structural and personal biases in the education system that prevent these students from reaching their full potential.

Building on these frameworks, Scott and colleagues have developed Culturally Responsive Computing (CRC) to translate the tenets of these approaches into a computing-specific theory (Scott & White, 2013; Scott et al., 2015). CRC posits that technological and digital innovation is possible for all students and is in fact enhanced when students have opportunities to reflect on their own identities and cultures. Providing a learning context that supports this reflection encourages students to understand the current biases in technological development and to use technology in innovative ways to address issues that are meaningful to them and their communities (Scott et al., 2015). It promotes a critical engagement with technology and the digital world amongst all students, highlighting key issues of equity and social justice and identifying how digital innovation can help to address these issues (Madkins et al., 2020).

Implementing culturally responsive approaches in computing

Initiatives aiming to implement culturally responsive approaches have tended to focus on extracurricular activities (e.g. Scott & White, 2013; Scott et al., 2015), or have incorporated a short sequence of lessons into a formal education setting (e.g. Eglash et al., 2011; Babbit et al., 2015). It is often difficult to evaluate these interventions due to small sample sizes or because they are targeted at specific groups rather than being embedded within the wider curriculum for all students. The largest-scale development and implementation of a curriculum for formal K-12 education using culturally relevant and equity-focused approaches in the US is the Exploring Computer Science (ECS) course. It was initially developed for Los Angeles school districts and uses a student-centred and inquiry-led approach to computing topics that are relevant to the urban high school students for whom they are designed (Goode, 2010).

The curriculum has been evaluated in recent years across five different states (McGee et al., 2018; Ryoo, 2019; Qazi et al., 2020). These studies have reported improvements in student engagement with the computing curriculum and both their perceived and objective learning gains over the course. Importantly, a key predictor in these learning gains was teachers' years of teaching the ECS curriculum (McGee et al., 2018). This may be due to increasing familiarity with the content, but is also likely to be related to the teachers developing understanding of the equity-focused principles underlying the curriculum and their ease in discussing complex and sensitive issues around race, bias and systemic barriers (Goode et al., 2020a, 2020b). The authors report changes in teachers' attitudes and openness to discussion during professional development courses before and after teaching ECS for one year. This highlights the importance of supporting teachers in implementing culturally responsive approaches in computing, which is central to the current experience report.

Supporting computing teachers

While the computing education community in the US has begun to focus efforts on developing culturally relevant, responsive and sustaining curricula for computing, the curriculum in England has not been derived from these principles. Across K-12 education, Newly Qualified Teachers (NQTs) consistently reveal relatively low confidence in teaching diverse groups of learners: in response to the question "*How good was your training in preparing you to teach learners from minority ethnic backgrounds?*" 51% of NQTs trained for primary and 56% trained for secondary teaching answered 'good' or 'very good' (Ginnis et al., 2018). In the Teachers' Standards for England, language specifically related to ethnicity and race are not evident, referring instead to "*pupils of all backgrounds*" (p.10) and "*tolerance of those with different faiths and beliefs*" (p.14, Department for Education, 2011).

In this context, we aimed to develop guidelines for computing teachers in England that introduced culturally relevant and responsive theory and practice, and provided practical examples from local curricula that they could use in their own teaching. The intention was to draw attention to systemic injustices and biases in the ways that technology is designed and used, and also to encourage students to use technology to address issues that are meaningful and important to them and their communities. To achieve this aim, we put together a working group of computing education researchers from the US, Canada and the UK, along with UK-based computing teachers. The next sections outline the process and outcome of the work of this group to produce the final guidelines.

The working group

A mixed group of practising computing teachers, academics, and practitioners in the field of computing education was established. This included two academics working in primary and secondary computing education respectively, and two invited academics from the US and Canada bringing international experience. Seven teachers were recruited to the study through an open call on local teacher networks and social media. An honorarium was offered to all members of the working group to facilitate their participation.

Two meetings were convened for all working group members. Prior to the first meeting, all participants were given reading material and resources to inform the initial discussions. The first meeting focused on the development of an initial idea of criteria that would support teachers in evaluating learning materials to ensure that lessons took account of culturally relevant pedagogy. A series of whiteboard activities, and small and whole group discussions was planned to engage all teachers, with a variety of prompts and mechanisms for detailed and accurate capture of contributions (see Figure 1).

Between the two meetings, three of the authors revised the criteria to develop a broader set of guidelines, drawing in the perspectives presented in the meeting. These were iterated and circulated again for comment, and then iterated again. In the second meeting, the invited academics led group discussions around the iterations of the guidelines. Participants collectively revised the third version of the guidelines and also considered the ways in which we could understand and develop our notions of 'culture'. All input was carefully captured in detail and represented in a fourth version of the guidelines. After the second meeting, these were again re-circulated and the final version developed.

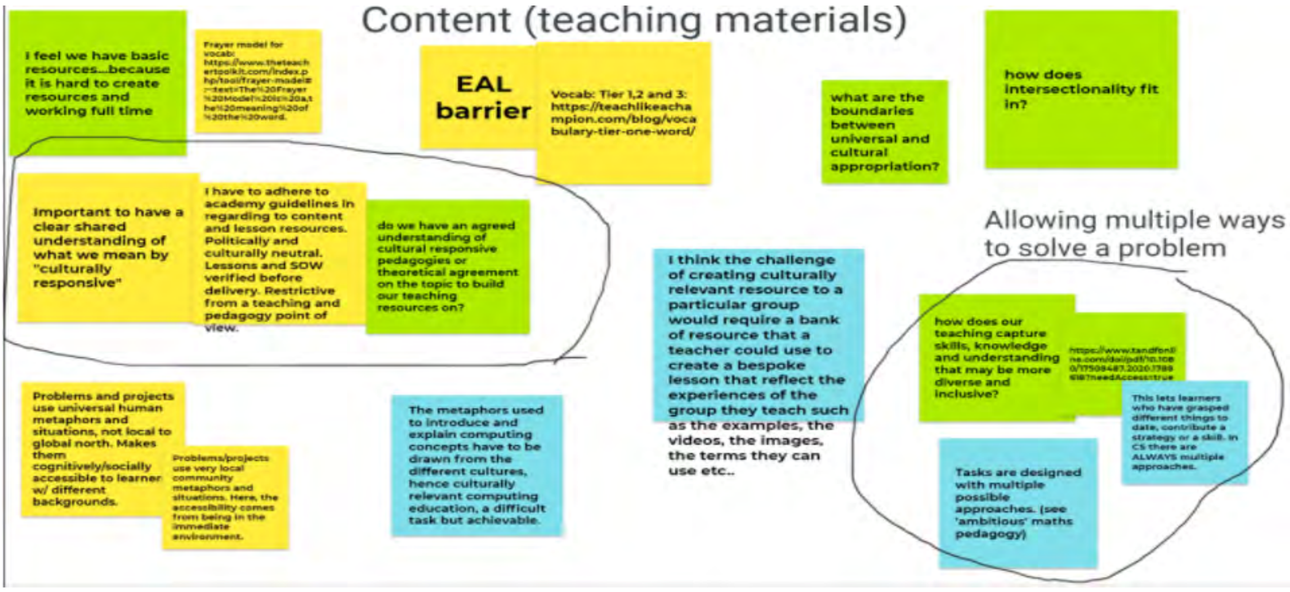

Figure 1. Use of discussion boards to ensure all participants' views were captured.

Table 1. Terms and definitions agreed by the working group participants.

Term	Definition
Culture	A person's knowledge, beliefs, and understanding of the world. It is affected by multiple personal characteristics, as well as social and economic factors.
Culturally relevant pedagogy	A framework for teaching that emphasises the importance of incorporating and valuing all learners' knowledge, ways of learning, and heritage. Promotes critical consciousness in teachers and learners.
Culturally responsive teaching	A range of teaching practices that draw on learners' personal experiences and cultural identities to make learning more relevant to them. Supports the development of critical consciousness in teachers and learners.
Intersectionality	The recognition that each person is made up of many identities in relation to gender, ethnicity, social/economic background, etc. People may be marginalised on the basis of one or more of these identities, and the effects of identifying with more than one characteristic may be multiplicative rather than additive.
Social justice	The extent to which all members of society have a fair and equal chance to participate in all aspects of social life, develop to their full potential, contribute to society, and be treated as equals.
Equity	The extent to which different groups in society have access to particular activities or resources, and to ensure that opportunities for access and participation are equal across different groups.

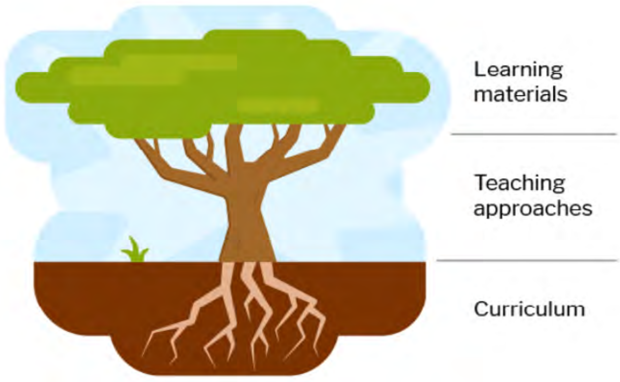

Figure 2. Teaching and curriculum design at three levels: curriculum (the roots), teaching approaches (the branches), and learning materials (the leaves).

The guidelines

The guidelines include a section on definitions (Table 1), followed by guidance under the three headings of curriculum, teaching approaches, and learning materials (Figure 2). The guidance also includes a discussion about issues facing computing teachers beyond their actual classroom practice and a set of resources for further reading. The resource can be downloaded as a PDF[11].

Curriculum

This includes the contexts in which computing concepts are taught, and how connections are made with issues that are meaningful to learners. The guidelines cover contextualisation and making connections. Examples of some of the prompts within this section are:

- How are computing topics discussed in relation to their social/historical/political context? For example, can you link the topic to pioneers of computing who have contributed to its development, or to current social justice issues?
- To what extent are there any specific issues in your local community that you could use to give real-world context to classroom computing concepts?

Teaching approaches

Equitable teaching approaches such as open-ended, inquiry-led activities and discussion-based collaborative tasks are key to providing opportunities for all learners to express their ideas and their identities through computing. Here the guidelines focus on making content accessible and relevant to all learners and to help them to express their own cultures and identities, providing opportunities for open-ended or inquiry-led activities, and promoting collaborative and structured group discussion. Examples of some of the suggestions within this section are:

- Have you considered industry perspectives and provided opportunities to hear from a variety of people working in industry or a variety of other careers?
- How have you encouraged learners to consider multiple perspectives when solving a problem? This can be achieved by sharing their code or projects with the class to show alternative methods for achieving the same end point.

Learning materials

In terms of learning materials, the guidance focuses on inclusive representations of a range of cultures and ensuring the accessibility of the learning materials to ensure that all learners feel that computing is relevant to them. Here the guidelines focus on representation and accessibility in terms of the language, images, videos and examples being used. Examples of some of the prompts within this section are:

- Are the names of the people/places in

[11] https://www.raspberrypi.org/blog/culturally-relevant-computing-curriculum-guidelines-for-teachers/

examples representative of a range of ethnicities, genders, cultures, and countries?
- Do the videos or images have captions that could be translated into multiple languages, and are transcripts available for the videos?

Next steps

This report has described a small-scale project made possible by the SIGCSE Special Projects scheme[12]. As well as providing a set of localised guidelines for a computing teaching community in an important area that has not previously been explored, we believe it will be useful for researchers and practitioners in other contexts to adapt this work for their own communities. We plan to engage with both teachers and learners to better understand how to implement culturally responsive computing teaching in the classroom, and to continue to develop the guidelines in line with our findings from this engagement.

A key component of successful implementation of culturally relevant pedagogy is raising teacher awareness and providing appropriate professional development to support teachers in understanding and delivering the approach in the classroom (Goode et al., 2020a, 2020b). Teachers need to be prepared to have complex and sensitive conversations with both colleagues and learners, and to acknowledge their own unconscious biases. This can be a difficult process, and is likely to require longer-term professional development: "A single 'equity' discussion is insufficient to surface more sophisticated and complex discussions." (Goode et al., 2000b, p.365). Teachers will need support in auditing their current teaching and identifying opportunities for incorporating culturally relevant pedagogy into their classrooms. Again, teachers' level of comfort in discussing and addressing issues is likely to differ between countries, and so we recommend that professional development and training should incorporate context-specific elements developed in collaboration with teachers themselves.

[12] https://sigcse.org/programs/special/2020.html

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Useful links

Raspberry Pi Foundation seminars:
rpf.io/research-seminars

Raspberry Pi Foundation research pages:
raspberrypi.org/research

Raspberry Pi Computing Education Research Centre: **computingeducationresearch.org**

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