The Impact of COVID-19 and “Emergency Remote Teaching” on International Computer Science Education Practitioners

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ABSTRACT

The COVID-19 pandemic has imposed “emergency remote teaching” across education globally, leading to the closure of institutions across all settings, from schools through to universities. This paper looks specifically at the impact of these disruptive changes to those teaching the discipline of computer science. Drawing on the quantitative and qualitative findings from a large-scale international survey (N=2,483) conducted in the immediate aftermath of closures, implementation of lockdown measures, and the shift to online delivery in March 2020, we report how those teaching computer science across all educational levels (n=327) show significantly more positive attitudes towards the move to online learning, teaching and assessment (LT&A) than those working in other disciplines. When comparing educational setting, computer science practitioners in schools felt more prepared and confident than those in higher education; however, they expressed greater concern around equity and whether students would be able to access the teaching made available online. Furthermore, while practitioners across all sectors consistently noted the potential opportunities of these changes, they also raised a number of wider concerns on the impact of this shift to online, especially on workload and job precarity. More specifically for computer science practitioners, there were concerns raised regarding the ability to effectively deliver technical topics online, as well as the impact on various types of formal examinations and assessment. We also offer informed commentary from this rapid response international survey on emerging LT&A strategies that will likely continue to be constrained by coronavirus into 2021 and possibly beyond.

CCS CONCEPTS

• **Social and professional topics** → **Computing education**; **User characteristics**; • **General and reference** → **Empirical studies**.

KEYWORDS

COVID-19, emergency remote teaching, practitioner perceptions, schools, universities, computer science education

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1 INTRODUCTION

1.1 The Impact of COVID-19

The impact of the COVID-19 (SARS-CoV-2) global pandemic is currently incalculable; it has affected, and continues to affect, profound social suffering, significant cultural disruption, and deep economic hardship. While indiscriminate in terms of whom it infects, it has largely punished society’s most vulnerable and less fortunate [44, 49, 50]; worse now, it appears that the virus may have to be tolerated on an indefinite basis [28].

The impact of the pandemic on education systems across the world has been profound [1, 47], presenting significant challenges for learning, teaching and assessment (LT&A), especially from a pedagogic perspective [19, 24, 40] – and how face-to-face learning is somehow perceived to be “higher quality” than online approaches [12, 37]. There have been significant responses from governments, organisations and institutions at all levels and settings internationally [53]; from major national policy initiatives to support learners and maintain quality and standards across all settings, to ongoing government inquiries on the longer-term impact of COVID-19 on education and children’s services.

1.2 The Rapid Shift to Digital

While there has been a rapid shift to “emergency remote teaching” during the pandemic, the general impact and efficacy of digital learning and educational technologies is still unclear in the formal academic literature, being dependent on specific educational settings and LT&A context. Whilst a range of international research studies have shown benefits of the successful application of digital LT&A across a variety of contexts and settings, the widespread adoption, implementation and evaluation of educational technologies has yet to be fully realised [11, 29, 30, 32]. The research and policy debate regarding the efficacy, utility and impact of educational technology and digital practice is ongoing, as exemplified by digital learning and teaching strategies and initiatives in schools, for example across the UK [18, 42] and the USA [48], as well as recent work on digital practice in higher education (HE) [27, 52]. We have also seen recent evidence assessments of remote learning [22], alongside guidance on how digital technologies can support learning [21].

1.3 Computer Science as a Discipline

It is clear that the academic discipline of computer science – and indeed the wider technology sector – has much to offer to address the breadth of societal challenges resulting from the COVID-19 pandemic; from computational modelling, the use of AI, machine learning and big data, as well as the wider legal, social, ethical and professional issues, such as from contact tracing, personal data sharing/storage, and the use of image recognition and surveillance [8–10, 20, 45]. There has also been recent analysis on the impact of COVID-19 on the international computer science research community – as we have seen across international scientific research communities more broadly [36] – especially on ongoing projects, careers, and dissemination of work [33]. However, there has been little focus on what this means for computer science education and practitioners, especially thinking about the range of specific disciplinary challenges for LT&A, across all settings and levels. This directly links to recent major international changes to computer science curricula, qualifications and practice (e.g. in the UK [6]), as well as the emerging focus on the required skills and infrastructure interventions to support the global post-COVID economic recovery [16, 23, 31].

We thus undertook an anonymous survey of international computer science educators on their perspectives as practitioners on the rapid shift to "emergency remote teaching" and transitioning online at the height of the COVID-19 crisis, and what they identify and forecast as its immediate and prospective impacts. The data was collected in the immediate aftermath of the forced institutional lockdowns and shift to online LT&A. It aimed to provide insight into emerging policy and practice; impact on practitioners, institutions and thus students; how might this change the discipline as a result; and what might this mean for the next academic year and in the longer-term. The analysis and discussion that follows is based upon the perspectives of n=327 practitioners drawn from across all educational settings, institutions, and the career hierarchy, and what they recognise to be the major consequences of COVID-19, the transition to online LT&A, and the challenges of maintaining "continuity of learning". Their accounts document the hopes and fears of the parts of the international computer science education community in the face of seismic and, as may prove to be, inalterable shifts. The majority of respondents tend towards a significantly more positive view of online migration than those working in other disciplines, recognising the opportunities and potential affordances of the crisis; these perceptions were consistent across all educational settings. There were some, albeit a minority, who raised a number of generalisable concerns on the impact of this shift to online and the challenges relating to their roles, their institutions and their sectors as a whole.

N.B. With regards to the consistent naming of the discipline through this paper, we use "computer science" to refer to the wider cognate discipline as represented by computing, ICT, informatics, etc, across all educational settings.

2 METHODS

2.1 Sample

The survey aimed to investigate how global computer science education practitioners have viewed the move to online LT&A. The sample was taken from a larger survey in which the target population was those who are actively involved in the delivery of LT&A within the education sector. Those who did not meet this criterion were excluded from analysis post-hoc.

We adopted a convenience sampling approach in distributing the Qualtrics survey whereby a link to the survey was shared via mailing lists of professional networks and related education organisations (for example, via ACM SIGCSE, and the UK Council for Professors and Heads of Computing, in addition to Twitter and LinkedIn). While the use of convenience sampling does not allow generalisation to a representative population, this sampling technique allowed us to document patterns within the observed population, with minimal time and cost restrictions.

After excluding those that did not meet the participant requirement, 2,483 international educational practitioners responded to the survey. This included 1,465 respondents from the HE (university) sector (59%) and 1019 respondents from schools (41%). 327 participants indicated that they taught computer science. This included 196 from the HE sector (59.9%), 131 from schools (40.1%).

The survey was launched on 26 March 2020 following the announcement of closures across various educational settings in the UK, Europe and USA, and closed four weeks later. Due to the distribution method we cannot calculate the response rate; however, of those who started the survey, 84.9% completed it.

2.2 Questionnaire

On the first page of the questionnaire, respondents were informed that the research was designed to identify their views and experiences of the move to online LT&A in response to COVID-19. The first section of the questionnaire consisted of demographic questions in order to determine how participant characteristics impacted key variables. In order to identify those who are computer scientists, those who responded that they worked in the HE sector were asked to select their discipline from a list created using the UK Joint Academic Coding of Subjects (JACS) codes[1]. Those who worked in schools were firstly asked if they taught a particular subject; those that responded that they did were then asked to select their subject from a list containing all curriculum subjects commonly taught in schools.

Demographic questions were followed by Likert and slider-scale questions exploring respondents' views of the changes. These included questions about how prepared and confident they felt about the move to online teaching. In addition, respondents were asked three open-ended questions in order to gain their overall insight into the impact of the changes:"*Please provide any comments of how the online learning and teaching changes brought in as a response to COVID-19 will impact upon*" followed by "*your role*", "*your institution*" and "*your sector of education*". Ethical approval for this study was obtained from the institutional research ethics committee. The survey was piloted on a subsample of the population before distribution to the wider international computer science community.

2.3 Analysis

Quantitative bivariate chi-square (χ^2) analysis of the key variables was conducted in order to determine overall attitudes to online LT&A and whether there were significant differences between those in computer science and those in other disciplines. Furthermore, comparisons were made between those in schools and HE in order to determine whether there were significant differences between those working in different educational settings. Chi-square tests were utilised due to the categorical nature of the variables and to

[1]https://www.hesa.ac.uk/support/documentation/jacs

assess whether the observed cell counts are significantly different from the expected cell counts.

Qualitative analysis of the open-ended questions used thematic analysis. Thematic analysis has been described as "a method for identifying, analysing and reporting patterns (themes) within data" [4]. This was done by firstly reading through the qualitative responses and numerically coding the data to identify whether comments were positive, negative or neutral. The responses were coded by two researchers to ensure inter-rater reliability (IRR=0.82). Within these codes potential themes were identified: "a theme captures something important about the data in relation to the research question and represents some level of patterned response or meaning within the data set" [4, p.82]. These themes were reviewed rigorously against the data to ensure that they were compatible with the data and accurately represented the comments.

3 RESULTS

3.1 Quantitative Data

Table 1 shows that those who work in computer science are significantly more likely to say that they felt prepared ($\chi^2(1)$= 31.47, p<0,001), confident ($\chi^2(1)$= 31.44, p<0,001), supported by their institution ($\chi^2(1)$= 9.91, p=0.002), held a good working knowledge of appropriate technologies ($\chi^2(1)$= 63.66, p<0,001), had access to appropriate technologies ($\chi^2(1)$= 23.24, p<0,001) and were confident that their students could access online LT&A ($\chi^2(1)$= 22.51, p<0,001). The figures presented in **bold** in both Table 1 and Table 2 had a z score of +1.96, meaning that this category were significantly more likely than expected to agree with the statement; the figures in *italics* has a z score of -1.96 meaning that this category was significantly less likely than expected to agree with the statement.

The information presented in Table 2 demonstrates that within those that responded that they worked within computer science there was also significant differences between education sectors. Those who work in schools (84.3%) were significantly more likely to say they were prepared than those in HE (69%) ($\chi^2(1)$= 8.39, p=0,004). Practitioners from schools (91.5%) stated that they were significantly more confident than those working in HE (78.7%) ($\chi^2(1)$= 7.62, p=0,006). Finally, those from schools (39%) were significantly less confident that their students would be able access online LT&A than those from HE (57.6%) ($\chi^2(1)$= 8,2, p=0,004).

3.2 Qualitative Data

3.2.1 School Practitioners: Positive Aspects.

> "*ICT has gone up massively as a valued skill - hopefully a trend that will be reflected and its impact will be increased in terms of curriculum timetabling.*" [Wales]

> "*We are in a pretty unique place because of what we teach.* " [New Zealand]

Mirroring the quantitative results, the open-ended responses from school practitioners highlighted the potential benefits that the move to online LT&A will have on education. As reflected in the quote above, respondents acknowledged the positive shift in emphasis on computer science as a subject: "*It may put further emphasis on computing as a subject, with so much technology in use*" [England].

Respondents also acknowledged the direct impact on their own role as a subject specialist in computer science: "*As ICT coordinator my role is probably more important now than when in school*" [Ireland]; "*As the resident IT expert, I'm everyone's new best friend!*" [England]. Thus, reinforcing the practitioner's own status in an expert in educational technologies.

Furthermore, respondents spoke positively not only about the impact on computer science as a discipline, but also about improvements in cross-curricular digital skills. School practitioners acknowledged the benefits of all staff upskilling in the area of digital technologies: "*Greater staff awareness of education technologies*" [New Zealand]; "*As Digital lead for the school it should make embedding some skills a lot easier as staff have now had a crash course*" [Wales]. More broadly, those in schools also mentioned the collegiate benefits of the whole school response to the change "*This is bringing our staff together in some ways because we are all collaborating and sharing ideas*" [USA].

3.2.2 School Practitioners: Negative Aspects.

> "*As a Computing teacher, most of my resources are already online. However, teaching programming techniques and complex concepts of computer science online is difficult.*" [UK]

However, while a number of positive messages came through, school computer science practitioners also raised a number of concerns about the impact of online LT&A. Reflecting the quantitative results, those in schools expressed concerns about students' access to the LT&A that would be made available online "*I will need to be more proactive in trying to reach students who may be struggling to cope. Some are homeless, some don't have laptops, some have less than ideal home situations*" [Ireland]. This particular concern was raised in response to the resource needed to study computer science "*[...] ensuring computing students have access to the internet and computers [...] and have all the essential software downloaded*" [Wales].

Furthermore, there was discussion about the appropriate pedagogy for teaching computer science "*For this year, since most of what needed to be covered has been covered for my AP classes, and since the AP Exams have been watered down a bit for this year, things are okay. But if I were to have to go completely to online teaching, I might as well retire. There's something lost if I can't interact with my students in a classroom setting. Assessment takes a real dive.*" [USA], this lack of face-to-face interaction was a key concern for school practitioners "*now that there is no face-to-face contact with students, the computer time is very demoralizing*" [USA].

More general concerns were also raised about the impact on staff workload "*I will be expected to provide additional content to support home learning*" [New Zealand]. Within this theme, while some practitioners acknowledged the benefits to the status of their role as an expert in education technology, others raised concerns about the impact of this on their workload "*So as well as being a teacher, I have set up the entire school platform, written how to guides for teachers, made tutorial videos and am doing online training to all other staff. It's supposed to be my holiday and I have worked all day every day*" [England].

Survey statement	Computer science n*	Computer science %*	Other disciplines n*	Other disciplines %*
"I feel confident in my ability to facilitate online learning, teaching and assessment"	**215**	**84.0**	*1071*	*66.5*
"My institution has been supportive in facilitating the move to online learning, teaching and assessment"	**220**	**86.6**	*1232*	*22*
"I have a good working knowledge of the technologies that are available to support learning, teaching and assessment online"	**246**	**90.8**	*1061*	*66.8*
"I can access appropriate technologies to support my online learning, teaching and assessment"	**265**	**95.0**	*1422*	*84.0*
"I am confident that all of my students will be able to access the teaching and assessment that I make available online"	*122*	*50.0*	**538**	**34.3**

Table 1: Responses to statements by discipline (*number and percent of those agreeing with statement compared to disagreeing)

Survey statement	School n*	School %*	HE n*	HE %*
"I feel prepared to deliver online learning, teaching and assessment"	**97**	**84.3**	*107*	*69.0*
"I feel confident in my ability to facilitate online learning, teaching and assessment"	**97**	**91.5**	*118*	*78.7*
"My institution has been supportive in facilitating the move to online learning, teaching and assessment"	89	85.6	131	87.3
"I have a good working knowledge of the technologies that are available to support learning, teaching and assessment online"	113	94.2	133	88.1
"I can access appropriate technologies to support my online learning, teaching and assessment"	111	94.1	154	95.7
"I am confident that all of my students will be able to access the teaching and assessment that I make available online"	*39*	*39.0*	**83**	**57.6**

Table 2: Responses to statements by sector (*number of percent of those agreeing with statement compared to disagreeing)

3.2.3 HE Practitioners: Positive Aspects.

> "*Overall, this may help us identify techniques that are particularly helpful in computer science education.*" [USA]

> "*I think that everybody will begin seeing value in technology's place in education.*" [UK]

As mirrored within the quantitative data, there were more positive themes emerging from the school practitioners. However, HE practitioners also recognised the positive impact of the changes on the computer science discipline. As demonstrated in the above quotes, some acknowledged the system learning that may now take place as a result of the rapid changes; one practitioner stated that "*computer science will boom*" [Canada].

Furthermore, the potential impact on the wider computer science sector was also acknowledged "*I expect to see an increase in the number of students in CS education, as CS jobs can typically be performed remotely (e.g. from home) and are therefore more resilient in the face of stay at home orders*" [UK]. Like with school practitioners, there was also acknowledgement that those within computer science are the best equipped to deal with these changes "*Computer science will be one of the least hit as our colleagues and students are among the most capable when it comes to operating online*" [UK].

> "*COVID-19 has been a lightning rod that has catalysed a lot of much needed changes in my institution.*" [UK]

Respondents from HE also mentioned the potential benefits to the HE sector as a whole: "*HE will never be the same. However, this might provide an opportunity to rethink the role of HE - to educate rather than to train?*" [USA]. One practitioner acknowledged the benefits on the changes to the structural relationships within their department: "*This disruption has had at least two strong internal advantages: Everybody has finally made an effort to transition to online learning; Older faculty have had to rely on the expertise of younger faculty (whom they were quick to dismiss until now)*" [USA].

Furthermore, there was acknowledgement that the work put in now may not be wasted in the longer term "*Everyone is likely to leverage the current move online as much as they can. Nobody is going to waste the work that they are suddenly having to do now*" [Canada]. However, as discussed below, there were concerns about the longer term move to online on the sector.

3.2.4 HE Practitioners: Negative Aspects.

> "*My role is shifting towards advising and away from teaching; a major challenge will be students' mental health, not their ability to write Java code.*" [USA]

> "*I am concerned that my institution thinks a move online is a move to more innovative and modern teaching, just by virtue of it being online.*" [England]

The key theme emerging from the HE practitioner responses was the fragility of the sector as a whole. Comments such as "*why would a student choose one school over another when everything is online?*" [Norway]; "*I am concerned about how this will impact recruitment and enrolment next fall*" [USA] and "*fear that some Universities may close*" [England] summarise practitioners concerns about the fragility of the HE sector as a whole within this climate. For computer science in particular, respondents raised concerns about the retention of staff "*Major financial impact is likely to lead to major staff shortages, particularly in my discipline, where graduates can all command high salaries in industry*" [USA] along with wider concerns about the potential impact on the industry: "*Produce less qualified graduates due to relaxed standards*" [USA].

Furthermore, respondents foresaw a longer-term move to online LT&A "*I think there will be greater pressure to do more online teaching. There will be an attitude that we were successful making this move in* *extraordinary circumstances. Surely, we can do the move permanently*" [Philippines] and "*I expect we will be asked to do more online teaching in the future, having now proven it can work*" [Nigeria].

For computer science in particular, there was concern about the access to specialist software needed for their courses: "*Access to specialist laboratories and equipment has been curtailed. Depending upon a student's specialism with Computer Science their experience could be more significantly affected. For example, those studying networking or robotics*" [South Africa]. In particular concerns were raised about the more practical aspects of a computer science programme in HE: "*Specifically I work in an area that involves some hands-on practical projects. These cannot be replicated online, so the student experience will be significantly changed*" [Scotland]. Furthermore, concerns were raised about how effectively certain aspects of computer science assessment can be done online "*the difficulty in assessing student's knowledge as code is easy enough to test when doing coursework*" [Wales].

> "*Increased workload (already VERY overworked) [...] it is easier for students to contact me (good) but means the volume of queries and contacts increases which saps time (bad). Need to do increased admin [...] All in all bad for my career as I can't do any science.*" [England]

As with school practitioners, concern was raised over the impact on workload. For those in HE there was particular concern about the impact on other aspects of their academic roles and responsibilities. In particular, respondents stated that "*research will be the hard part*" [England]; "*this has massively blown out the proportion of time I expected to spend teaching, and as such I am not engaging in the research I need to be doing*" [USA].

4 DISCUSSION

> "*This is the beginning of a new era. Things will never be the same again.*" [HE, USA]

4.1 Pedagogy and Practice

The quantitative data showed that those from computer science were significantly more positive about the move to online LT&A in the immediate aftermath of education closures, then those from other disciplinary areas. These results are, perhaps, unsurprising, given the likely proficiency of computer scientists to use technology. However, they highlight that this confidence with technology translates to its use for online LT&A. When this was broken down further, while those from schools felt more prepared and confident in their ability to deliver online LT&A, they were less confident about their students' ability to access the material.

> "*This is bringing our staff together in some ways because we are all collaborating and sharing ideas. My principal has been great about communicating with us on a daily basis.*" [school, England]

Central to both the positive and negative commentary was high-quality learning and teaching for computer science, and especially appropriate pedagogic approaches. While some recognised the potential that moving teaching online could allow practitioners to be 'flexible' and 'creative' with their pedagogy, fostering increased collaboration between teams, practitioners expressed concern about how key foundation topics and threshold concepts in computer science can be taught effectively without face-to-face instruction. Therefore, while some literature has demonstrated the use of technology to enhance teaching, a number of practitioners were concerned about its value and contribution to computer science education, especially for key topics in computer science, such as programming and mathematical foundations, as well as more practical or collaborative topics such as robotics and group software projects.

4.2 Bridging the Skills Gap

> "*As a Computing teacher, most of my resources are already online. However, teaching programming techniques and complex concepts of computer science online is difficult.*" [school, Wales]

> "*HE will move increasingly to online provision, sadly. Our technologies do not currently allow the creation and manipulation of shared mental representations which is necessary for effective teaching and learning of mathematics and computer science.*" [HE, England]

Yet, it could also be argued that the efficiency of online teaching may be overplayed by institutions. This may be particularly true of schools, who may be rapidly moving to teaching online, without the necessary robust digital infrastructure, professional development and understanding of effective online pedagogy. As noted in the responses, there may be longer-term positive impact of this technological upskilling of educational practitioners, however, significant concerns were raised about the impact on workload due to these changes. There were also concerns raised about top-down, "one size fits all" institutional approaches, rather than evaluating and addressing disciplinary-specific challenges and supporting appropriate pedagogic approaches.

4.3 Infrastructure

> "*Delay in critical upgrades to servers and increase in infrastructure. Need to expend further funds to have suitable hardware to loan to staff in these circumstances.*" [school, England]

Another theme that was acknowledged as a significant challenge was the demand on educational digital infrastructure. While practitioners acknowledged the potential opportunities of institutional financial investment in digital infrastructure, concern was raised about equity of access to these recourses. While it was acknowledged by some HE practitioners that computer science students may be the least affected by this, there was broader concern for those that may not be able to access appropriate technologies (especially if there was a requirement for specialist equipment or software), and that it was easy to make assumptions about how and when students are able to engage with online learning. This concern was more consistently expressed by school practitioners.

> "*The difficulty is how to provide alternatives to specialised laboratory provision. We also have large numbers of international students, some of*

> *whom have now gone back to their home countries. Some of these have very poor or no access to technology and keeping in touch with them is challenging. Luckily our sector of education, computer science, means that both staff and students tend to have good knowledge of digital technologies and how they can support online learning but care still needs to be taken as not all students have good access from home or can adapt easily to an online version of education.*" [HE, UK]

4.4 Limitations

It is also necessary to identify the limitations of this research and to highlight the potential for how it can support future research in this area. As this research was conducted in the immediate aftermath of the move to online LT&A it could be argued that, due to the rapid changes in the situation since March 2020, attitudes may have changed since this data was collected. Furthermore, this study has grouped together international computer science practitioners from across various educational settings. It could be argued that the difference in experience of these practitioners is vast and, consequently, it is difficult to recognise them as a homogenous group. However, the coherence from the quantitative and qualitative results offers some strength to the insights into international computer science education practitioners' perceptions during these radical changes. The results highlight the longer-term opportunities and challenges that the move may bring about. Furthermore, follow-up research should be conducted in order to better understand how perceptions have changed since this data was collected.

5 CONCLUSIONS AND LOOKING AHEAD

Many of the challenges and opportunities presented by COVID-19 and the rapid shift to "emergency remote teaching" as identified in this survey could be applied more broadly across the various international educational settings. In particular, there are significant concerns regarding impact on job precarity and security, career progression, financial sustainability of institutions [51], robustness of the qualifications and examinations system, issues of equity and access to technology, as well as the health and well-being of practitioners and students due to increased workloads and expectations. However, it was clear that school practitioners were frequently more positive due to the perceived rise in status of their "key worker" role and for their discipline more generally. It is also important to acknowledge the ongoing media narrative regarding online teaching being perceived as lower quality than face-to-face teaching (especially for HE) [12, 37]; however, teaching quality is more important than how lessons are delivered [22], while technology can be used to improve the quality of explanations and modelling, and can play a role in improving assessment and feedback [21].

The rapid adoption of digital technologies for almost all activities that could previously have taken place within the physical space of an educational institution presents opportunities to rethink how many academic practices might take place in virtual environments. These resultant shifts in culture, identity, and new demands on educational leadership and management – especially in schools [26]) – and perhaps specific challenges for computer science as a discipline. However, reshaping the post-pandemic digital structure of education also risks exacerbating existing inequalities in the use of digital technologies and opening up new areas of academic life to surveillance and control [7], directly linking to wider priorities surrounding the importance of legal, social, ethical and professional issues in computer science education.

However, there are a number of specific issues for computer science practitioners that provides valuable insight and context for the discipline as we move with some uncertainty towards the next academic year and beyond. In particular, the increased prominence of technology in an educational context provides opportunities for showcasing the importance of cross-curricular digital and data skills, as well as the explicit value of computer science as a STEM academic discipline. This clearly resonates with recent international computer science curricula and qualifications reforms, especially as computer science is starting to become increasingly established as a school-level subject [3, 6, 25, 39]. There is also an increasing focus on identifying and refining effective pedagogic approaches for LT&A on key foundation topics in computer science – and especially for CS1 – such as mathematical foundations, programming and cybersecurity [13–15, 17, 34, 38, 43]. However, there are concerns of top-down, "one-size-fits-all" institutional or national approaches that do not recognise the unique characteristics of LT&A in computer science across the various settings and levels. Further work is required to better identify, evaluate and share best practice for some of these areas, especially with regards to assessment, certification and qualifications.

Finally, it is clear there will be a huge demand for digital skills and infrastructure [2, 16, 46]. to support the global post-COVID economic renewal [35]. Recent evidence from the UK suggests that young people are more interested in science and technology careers as a result of COVID-19 [5], alongside opportunities to promote cross-curricula and interdisciplinary approaches in school STEM lessons when addressing wider societal issues [41]. Based on the data obtained from this rapid response survey of international computer science practitioners, we anticipate further evaluation and development of best practice for online LT&A for computer science as we move into the 2020-2021 academic year and beyond. Furthermore, it is imperative that follow-up studies are conducted to capture the longer-term impact to computer science education, especially as it appears that the virus may have to be tolerated on an indefinite basis [28].

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