6 Accessible, innovative and high-quality infrastructure for digital education

The chapter covers recent developments related to the provision of accessible, innovative and high-quality digital infrastructure across education systems. It finds that a range of challenges remain to ensure equity in access to digital infrastructure, and that current levels of investment in innovative education technologies are likely to be insufficient. The chapter recommends that governments should further invest in digital infrastructure that promotes equitable learning opportunities and seek to boost investment and innovation in education technologies through multi-dimensional and co-ordinated innovation, entrepreneurship or funding policies.

Introduction

The success of digital education strategies hinges upon wide and equitable access to digital infrastructure, including connectivity, hardware, software, tools and services. All students, teachers and schools should have access to at least a minimum extent of high-quality technologies that are a prerequisite for digitally enabled education systems. This chapter examines the availability and adequacy of digital infrastructure for education, with a focus on accessibility, equity of distribution (e.g. across education institutions and students) and quality (e.g. in terms of Internet speed, broadband width or computing power). Whilst much of the available data on digital education infrastructure stems from prior to the COVID-19 pandemic, education systems have made significant advances in their digital infrastructure in recent years. This chapter considers how policies can further advance the availability and accessibility of this digital infrastructure and foster innovation to reap the full benefits of cutting edge digital tools for education.

Reliable connectivity for all is the foundation of digital education. Ensuring quality and equity in schools' Internet access and learners' home Internet access requires overarching policies to promote and facilitate adequate broadband deployment, and more targeted efforts by education ministries. Such efforts can include providing funding to education institutions for affordable broadband and extending Internet reach to all education institutions and students, including learners or schools in remote locations.

Beyond connectivity, there is also a need to ensure widespread access to quality digital equipment (hardware and software), tools and services. Successfully targeting equipment gaps requires a comprehensive policy approach with a strong capacity building component targeted at education institutions, teachers, students and parents. Capacity building might entail building partnerships with a range of stakeholders (e.g. private sector, statistics institutes, and local communities) and mobilising knowledge networks.

Policy makers should not only ensure the access to quality digital infrastructure today but anticipate how digital tools can support teaching and learning in the future. In this respect, governments play a key role in creating the conditions that can promote innovation in digital education technologies, including through general policies to stimulate entrepreneurship, and stimulating both public and private investment in the development of education technologies. Providing support to access finance and business investment, setting up innovation funds and providing grants for digital education technologies' development and innovation as well as supporting education technology incubators or accelerators are among the policy levers that governments may consider to sustain a dynamic education technology sector. Governments may also aim for monitoring developments in the education technology industry to ensure sufficient investments and inform innovation-related policies for digital education technologies.

Building the necessary infrastructure for digital education thus comes with a range of challenges which this chapter aims to address by analysing existing evidence and presenting promising policy examples from OECD and EU countries. Some of the key questions on this issue that policy makers need to consider include:

- How can education systems support access to fast and reliable Internet connection for all schools, teachers and students?
- How can education systems provide access to quality digital education equipment (hardware and software) in schools and at home for all learners while anticipating further investment and maintenance needs?
- How can education systems stimulate private investment in and support innovation of hardware, software and services?

Recent developments and current challenges

Despite progress in coverage and take-up, fast and reliable Internet connection is not yet accessible to all communities and learners

Substantial disparities persist in access to and quality of Internet connection in learners' homes

Network connectivity in education institutions and at home, whether through mobile/fixed networks or communication satellites, is essential to digital learning activities, student-teacher digital interaction and the interoperability of systems. While speed and capacity requirements vary across tools, stable high-speed broadband connectivity with low latency (i.e. the time it takes for data to travel between sender and receiver) is necessary for both real-time (synchronous) online interactions asynchronous (i.e. self-paced) virtual learning. Indeed, with the exponential rise of data and audio-visual content, only a stable, high-speed connection is a useful one. Adequate wireless broadband connectivity is also needed to ensure full connectivity in large physical learning spaces such as university campuses.

The pandemic accentuated the need for access to institutional networks from home or other places of study (off-site), increasing the role of public wired networks (including fibre) and mobile data access (4G, 5G, satellite) of adequate speed and reliability for online access to learning. The extent to which internet connectivity can be considered adequate and reliable for learning needs will vary depending on the connection speed, the type of learning activity, the extent to which there is contention for the available bandwidth from other devices or household members and (in the case of mobile data) caps or limitations on data imposed by mobile data providers. For example, online meeting software such as Zoom uses up to 900 MB of data per hour in group calls – and more than 2GB of data per hour in high-definition mode (Holslin, 2021[1]). High-speed network connectivity is considered to not only be necessary for performing digital learning activities; it can also support better learning outcomes (Sanchis-Guarner, Montalbán and Weinhardt, 2021[2]) the transition to higher education (Dettling, Goodman and Smith, 2018[3]) and online learning uptake in higher education (Skinner, 2019[4]).

According to the 2022 European Union's Digital Economy and Society Index (DESI): 78% of households had broadband; 90% had fast broadband (Next Generation Access or NGA) (but only 41% had access to fast – at least 100 Mbps – fixed broadband); 87% had mobile broadband; 66% had 5G coverage; while 70% had Fixed Very High Capacity Network (VHCN) coverage (European Commission, 2021[5]). The DESI index (which combines fixed broadband take-up and coverage with mobile broadband indicators and prices) ranges from over 60 (out of a maximum of 100) in Denmark, the Netherlands and Spain, to under 40 in Bulgaria and Greece.

In terms of network technology trends, 2021 data for 38 OECD member countries show different technology mixes coupled with a strong move towards fibre, which now makes up 32% of fixed broadband subscriptions (20 percentage points more than a decade ago) (OECD, 2022[6]). While mobile broadband expanded considerably as a result of the pandemic, growth is now more stable compared to a decade ago, due to a greater take-up of fixed networks, in part because of their greater reliability for study, work and leisure. The deployment of 5G networks in EU countries advanced rapidly during the pandemic: 5G commercial services are now available in all 27 EU member states, with 62% of Europeans reached by a 5G network in 2021 (compared to 30% in 2020) (5G Observatory, 2022[7]). Connectivity at home was critical in enabling students to remain connected to their teachers and peers and continue learning online during the COVID-19 pandemic. On average across OECD countries, 96% of 15-year-old students reported having access to an Internet connection at home in 2018 (OECD, 2019[8]). In EU countries, less than 1% of surveyed students in PISA (2018) did not have an internet-connected mobile phone in their household. Inequities in access to Internet at home remain, however, in a number of OECD countries.

Fewer students from socio-economically disadvantaged schools[1] benefitted from an Internet connection at home than their peers in socio-economically advantaged schools in Bulgaria (6% gap in the share of students with an Internet connection at home between students from socio-economically advantaged and disadvantaged schools), Greece (9% gap), Malta (5% gap), the Slovak Republic (6% gap) and Romania (9% gap). Similar gaps were observed between students in rural and urban areas in Bulgaria (8%), Greece (10%), Hungary (9% gap) and Romania (11%).

For higher education, there are no comprehensive cross-country statistics on differences experienced by learners in their household connectivity. However, available national evidence also points to gaps in accessibility. For example, evidence for Ireland during the pandemic showed one in six students came from areas with poor broadband coverage, with those in the areas with poorest broadband coverage being more likely to be socio-economically disadvantaged (Cullinan et al., 2021[9]). A survey of 511 entrants to higher education during the pandemic period in the UK also indicated that while, on average, only 7% reported having insufficient access to the Internet, this percentage rose to 12% among those from lower socio-economic households (Montacute, Rebecca; Holt-White, Erica, 2020[10]).

High-speed Internet connection is not yet the norm in all communities and schools

Across all OECD countries and economies, quality Internet access in schools is positively correlated with student performance and equity in reading[2], even after accounting for GDP per capita (OECD, 2020[11]). More generally, countries and economies with fewer material resource shortages, in particular education materials (e.g. digital equipment, textbooks)[3] tend to display better performance in PISA assessments. In addition, countries and economies that have smaller differences in material resources between advantaged and disadvantaged schools also display higher reading performance levels. Education institutions can help narrow connectivity access gaps in countries where socio-economic background or geography impact Internet access at home. Access to the Internet in schools was almost universal in 2018 in OECD and EU member countries and has likely increased even further since the pandemic. More than 96% of school computers available to students across OECD countries were connected to the Internet, according to school principals' reports in PISA 2018 (OECD, 2019[8]). Socio-economically advantaged schools tend to have larger shares of computers connected to the Internet in Colombia (43% gap), Costa Rica (17% gap), Iceland (6% gap), Lithuania (2% gap), Luxembourg (5% gap), Mexico (42% gap) and Türkiye (16% gap). In contrast, the rest of OECD countries displayed no statistically significant gap in students' access to internet-connected school computers for education purposes by school socio-economic profile.

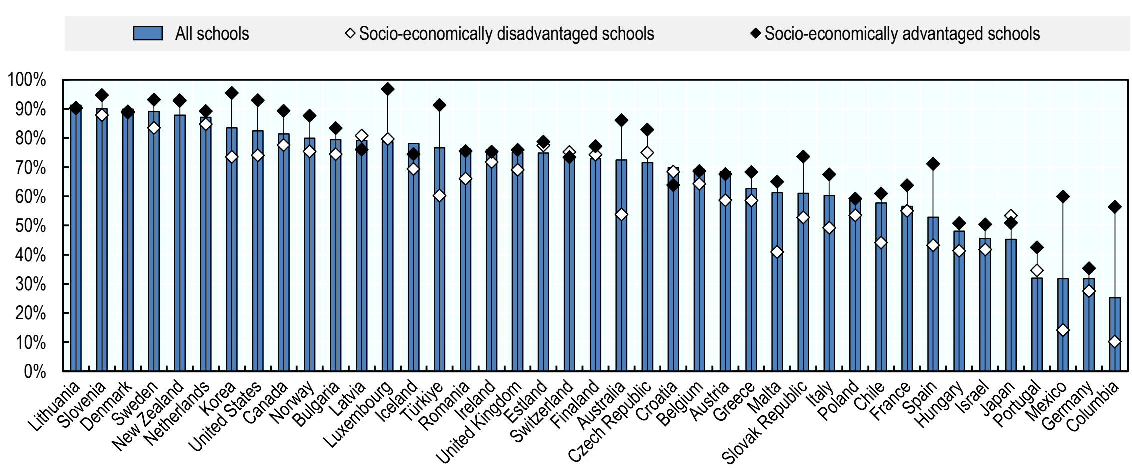
However, the mere availability of Internet connection is not sufficient to support student learning, unless adequate Internet speed is also guaranteed. Many students in OECD countries lack access to high-speed Internet in schools: in 2018, nearly one-third of 15-year-olds in OECD countries were in schools where the principal reported that the school's Internet bandwidth or speed was insufficient (Figure 6.1). Analyses based on PISA (2018) show that principals in schools with a high share of socio-economically disadvantaged students are also less likely to report that their school benefits from high-quality Internet connection. In 2018, in OECD and EU countries, gaps in access between socio-economically advantaged and disadvantaged schools were as high as 32% in Australia, 46% in Colombia and Mexico, 18% in Italy, 24% in Malta, 21% in the Slovak Republic, 28% in Spain and 31% in Türkiye. Data from the 2022 PISA round will show whether the broad investments in schools' digital infrastructure since the pandemic have helped to narrow these gaps.

Among European countries, according to the most recent available data prior to the pandemic, the share of schools benefitting from fibre optic cable connection was on the rise, but only around 32% of students in primary schools, 40% in lower secondary schools and 51% in upper secondary schools had Internet access through fibre optic in 2017-2018 (European Commission, 2019[12]). The remainder of schools were mostly connected through ADSL, followed by cable connections, and only a minority of schools had satellite connections. In addition, cross-country inequalities in students' access to fibre optic in schools remained particularly large before the pandemic (European Commission, 2019[12]). Evidence from PISA (2018) on principals' perceptions on the adequacy of Internet connection speed in their schools shows that while high-speed Internet connection was available to 9 in 10 students in Lithuania, only 1 in 3 students in Germany and Portugal were in schools whose principals reported sufficient Internet speed in 2018 (Figure 6.1). While more updated data is not available, it is likely that the share of education institutions with fibre optic connections has substantially expanded in the ensuing years, given that the share of European households with fibre optic cables tripled between 2017 and2022 (Observatorio Nacional 5G, 2022[13]).

In addition, inequalities in access to a fast Internet connection persist also across geographic areas within countries. In 2018, students attending schools in rural areas were, on average, less likely to benefit from high-speed Internet and to connect to the Internet through fibre optic (European Commission, 2019[12]). Some countries also display particularly large gaps in access to quality Internet connection between students in rural and urban schools. Gaps in access between students in rural schools and those in urban schools were as high as 28% in Costa Rica, 30% in Mexico, 44% in Romania and 21% in Slovenia (OECD, 2019[8]).

Figure 6.1. Sufficient Internet bandwidth or speed in schools, by school type

Percentage of students whose principals agree or strongly agree that the school's Internet bandwidth or speed is sufficient to enhance teaching and learning with digital devices, by school type



Source: Adapted from OECD (2018[14]), PISA Database 2018, https://www.oecd.org/pisa/data/2018database/ (accessed 20 May 2022)

StatLink https://stat.link/sj7n21

Challenges remain to ensuring equity and quality in learners' access to digital education equipment

> *While access to computers in schools is almost universal in OECD countries, most schools are not highly equipped with digital tools*

Access to computers for education purposes was extensive in OECD countries. On average across schools in OECD countries in 2018, there were 0.8 computers available for education purposes for every

15-year-old student, and the computer-student ratio had largely increased since 2009 (OECD, 2020[11]). However, challenges remained with respect to making these computers widely accessible to students in all learning situations. On average across OECD countries, only 40% of computers were portable (e.g. laptop, tablet), although this share is increasing. Northern European countries (Denmark, Norway and Sweden) feature the highest share of portable computers, reaching up to 98.4% of students in Sweden, followed by the United States (79%) and Australia (74%) (OECD, 2020[11]). Similarly, only a third of lower secondary students in the EU had access to desktop computers within the classroom. Instead, most students tended to access school desktop computers in school laboratories, which may limit the potential of digital technology use in regular teaching and learning activities beyond IT classes if school desktop computers are the only devices students have access to at school (European Commission, 2019[12]).

Previous European surveys have developed the concept of "digitally equipped and connected schools" with respect to schools' levels of connectedness and access to digital equipment[4] and highlighted broad cross-national variation in the share of these schools. In European countries with available data, students from Nordic countries and at higher levels of education are more likely to attend schools that are well-equipped in terms of fully operational equipment (e.g. computers, interactive whiteboards), connected to high-speed Internet and with access to a range of digital content related sources (e.g. virtual learning environment, a platform for online school-home communication) (European Commission, 2019[12]). In addition, on average across EU countries, the share of digitally equipped and connected schools is higher at higher school levels.

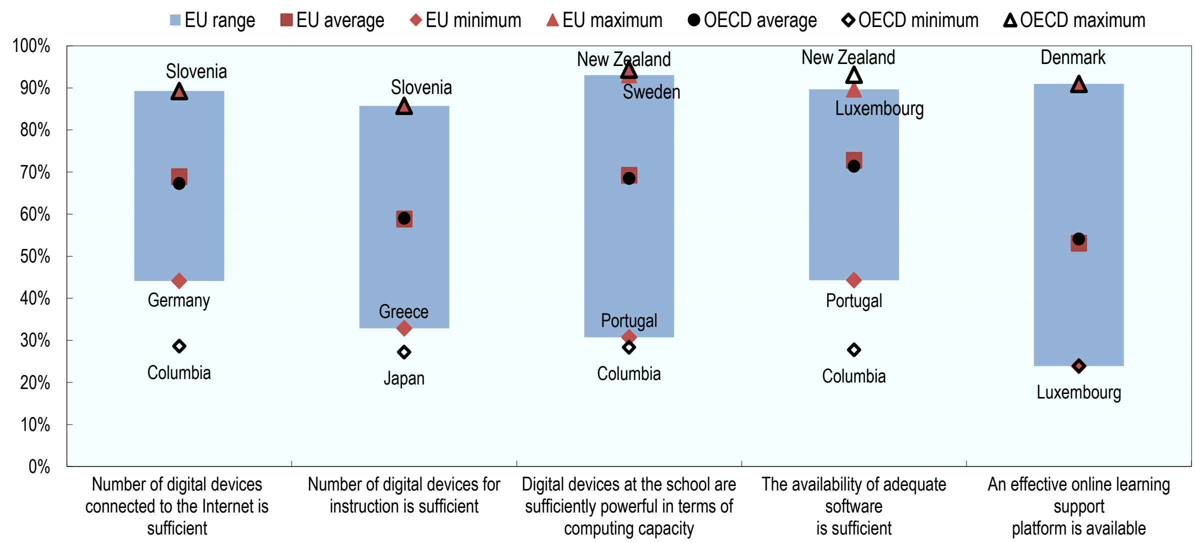
The quality of digital equipment available in education institutions is highly variable between and within OECD countries

The mere availability of digital equipment is insufficient to support student learning if computers are old or education software inadequate. Data from PISA (2018) provide evidence on the perceived sufficiency and adequacy of specific digital technologies available for learning and teaching in schools (Figure 6.2). While students' overall access to school desktop computers was widespread across OECD countries, school principals did not perceive that the number of digital devices for instruction was sufficient (OECD, 2019[8]). This raises questions about the adequate distribution of computers within the school premises and availability of computers for regular instruction, although countries might have advanced on these issues since the COVID-19 pandemic. Similar questions emerge also with respect to the quality of digital equipment available in schools. In European countries, only around 60% of lower secondary school students in Europe were in schools where more than 90% of the equipment (desktop computers, interactive whiteboards, laptops/notebooks and mobile devices) was fully operational, with large cross-country differences (European Commission, 2019[12]).

Within-country inequalities in access to equipment of sufficient quality also exist. On average across countries, perceptions of shortages or inadequate digital technologies are more recurrent among students from disadvantaged schools. For instance, the gap between the percentage of students from disadvantaged schools and those from advantaged schools accessing powerful digital devices at school is 29% in Colombia, 17% in Hungary, 36% in Mexico and 21% in Spain (OECD, 2019[8]). TALIS data depict similar inequities based on the views of school principals: the shortage or inadequacy of digital technology (e.g. software, computers, laptops and smart boards) is more likely to hamper the quality of instruction in schools with a large concentration of socio-economically disadvantaged students (OECD, 2022[15]).

Figure 6.2. Adequacy of digital technologies in schools

Percentage of students in schools whose principal agreed or strongly agreed with the different statements about the school's capacity to enhance learning and teaching using digital devices



Source: Adapted from OECD (2018[14]), PISA Database 2018, https://www.oecd.org/pisa/data/2018database/ (accessed 22 May 2022)

StatLink https://stat.link/f90rxj

In HEIs students generally appear to enjoy wider access to campus-based digital infrastructure, compared to schools. HEIs have access to NREN-provided high-speed Internet connectivity and have achieved near-universal adoption of VLEs. In the United Kingdom, for example, all but 3% of HEIs reported VLE adoption in 2022 (Mosley, 2022[16]). The offer of open-source VLEs, such as Moodle, also provides wide access to a basic VLE for HEIs.

Divides in access to digital equipment at home persist in OECD countries

Despite recent advances in connecting individuals and students, divides in access to digital equipment at home persist in OECD countries and were a major challenge during the COVID-19 pandemic. As the pandemic forced students to study from home, gaps in access to digital technologies from home became important obstacles to learning activities and left some students behind. For example, in an April 2020 non-probability survey conducted by the European Students Union, among 17 000 higher education student respondents, about 10% reported facing some difficulties with access to a home computer, and 60% reported facing some difficulties securing a high-quality home Internet connection (OECD, 2021[17]). In addition, a survey of 114 European HEIs showed that almost half of them had to take action to address digital divides among their students in the first three months of the pandemic (OECD, 2021[17]).

When school computers are not portable, the availability of digital equipment at home becomes crucial to enable students' access to learning opportunities. In this respect, prior to the pandemic, around 93% of 15-year-old students in OECD countries reported having access at home to a computer that they could use for schoolwork (PISA, 2018). On average across the OECD, students from socio-economically disadvantaged schools were less likely to have access to a computer for schoolwork at home (14% gap)

(PISA, 2018). In Mexico, around 24% of 15-year-old students from disadvantaged schools had access to a computer for schoolwork at home, in contrast to 87% of students in advantaged schools.

In higher education, there are no comprehensive cross- and within-country statistics on the number of students who lack access to digital equipment at home that is adequate to learning needs. A 2018 study based on a non-representative survey of 748 students in U.S colleges found that 20% of students had difficulty maintaining access to technology, with higher incidence amongst students of lower socio-economic status and students of colour (Gonzales, McCrory Calarco and Lynch, 2018[18]). More recent large-scale survey evidence for the United States in 2020 showed that about one in four higher education students experienced device issues including outdated devices that could not support the needed software and apps, and having to share a device (Brooks and Gierdowski, 2021[19]). In the United Kingdom, a 2020 study on 1 416 higher education students showed that 18% were impacted by lack of access to a computer, laptop or tablet and 56% lacked access to appropriate online course materials (Office for Students, 2020[20]).

Divides also persist in students' access to education software and learning platforms

Digital devices are the first step to accessing an ever-increasing number of digital tools and services. Digital education platforms, education software and learning apps are a few examples of tools upon which students can rely. Around half of EU students at lower secondary level had access to a VLE at school before the pandemic and most of them could access the VLE outside of working hours or outside the school premises (European Commission, 2019[12]). However, differences in access across countries are evident – no more than 15% of students had access to VLEs in Croatia, Greece, Hungary and Romania, in contrast to more than 90% in Finland and Sweden.

Before the pandemic, the share of students with access to education software at home had stagnated across countries with available PISA data. In 2018, 58% of 15-year-olds in OECD countries had access to education software at home, with students from socio-economically advantaged schools displaying substantially higher levels of access (OECD, 2019[8]). As learning moved outside of school premises during the pandemic, education technologies targeted directly at students or their parents (rather than at formal education institutions) experienced a rise in demand (HolonIQ, 2020[21]). However, as in the pre-pandemic period, socio-economically advantaged students who could afford to purchase such software are likely to have had greater access to these technologies except where government schemes supported students' access.

Advanced technologies are not yet commonplace in education systems

Beyond standard or traditional digital equipment (e.g. digital devices), education systems increasingly have access to a range of new and more advanced digital tools and products developed by EdTech companies (e.g. Augmented Reality, Virtual Reality, AI, robotics and blockchain). Despite their potential for transforming education in schools and classrooms, such technologies have not become mainstream in education systems yet. In fact, the gap between the technology available to most education stakeholders and the most advanced, forward-looking types of technology remains wide (Vincent-Lancrin, Cobo Romaní and Reimers, 2022[22]).

There are many reasons for this slow adoption of the most advanced education technologies. Firstly, their adoption can be prohibitively expensive for many education institutions. For example, virtual and augmented reality implementations require the purchase of costly specialised equipment and software, while the integration of advanced robotics requires both the purchase of robotic equipment and the availability of staff trained in its programming and use.

Furthermore, as discussed earlier in this report, AI-based software is raising ethical dilemmas within education systems, and there is increasing awareness of the need to carefully monitor the impact of the use of AI and algorithms in education settings. Education institutions and policy makers also face a steep learning curve in understanding the strengths, weaknesses, opportunities and challenges posed by AI (Holmes et al., 2022[23]). For example, the emergence of advanced generative AI chatbots has sparked widespread deliberations about the implications for education systems, in terms of impact on students skill development, assessment processes, and the definition of learning goals and curricula (Dwivedi et al., 2023[24]).

Finally, it should be noted that the adoption of advanced technologies can further widen inequalities between students of different backgrounds if these are more likely to be accessed by socio-economically advantaged education institutions or students, who also likely benefit from better digital technologies conditions, and better-prepared teachers and school leaders. Research evidence suggests that even for relatively less novel or advanced technologies, such as school-to-parent communication technologies, equity considerations are critical as technology adoption is higher among the most advantaged families (Bergman, 2019[25]).

Policy makers and educators are therefore concerned with how to harness the potential benefits of advanced technologies while mitigating its risks and the scale of investment required. However, the number of use cases for such advanced technologies is continuously increasing (Educause, 2022[26]) providing more opportunities to learn from existing practices.

Cloud services are fast becoming mainstreamed, but adoption of cloud technologies in education systems is uneven

Cloud services including cloud storage, Infrastructure as a Service, and Software as a Service have not been rapidly adapted in education. Suppliers of core software have moved to Software as a Service models of delivery: for instance the four main global VLEs – Canvas, Brightspace, Blackboard, and Moodle are already cloud-hosted and supported, or are rapidly moving towards that model. While many education institutions have remained reluctant to 'lose control' of their software, the pandemic showed that on-premises server capacity cannot handle an unexpected large surge in demand, thus creating disruptions in learning when capacity is limited.

The potential of cloud services to bridge inequality in access relies on having access to fast and reliable network connectivity. Cloud services can be accessed anywhere (i.e., they are location-independent), benefit from economies of scale, reduce the need to run local IT services, and grant access to many independent users to better and more varied portfolio of resources (Géant, 2020[27]). Digital divides in broadband infrastructure mean institutions located in areas of poor connectivity will fall behind in the transition to the cloud and its benefits.

Further investments are needed in the innovation of education technologies

Education technology venture capital funding has surged since the pandemic, but investment in digital innovation for education is likely insufficient

Achieving the potential of digital technologies in education requires providing access to quality digital technologies to all students and educators. In turn, this demands significant investments to develop the innovative tools, products and services that can truly enhance learning outcomes. Investors in the EdTech market span a spectrum of organisations, including philanthropic foundations, venture capital, government and government intermediaries as well as idea incubators (e.g. EdTech competitions) (Escueta and Holloway, 2019[28]). However, systematic data on the amounts invested in education technology by most investor types are often lacking, with most existing evidence focusing on venture capital investments in education technology (hardware, software and technology-enabled services). Governments can also intervene by injecting public resources in venture capital markets.

Disaggregated data on government-sponsored venture capital in education technology is not available. Yet, available data on venture capital investments show that over the past decade, venture capital has become increasingly involved in the funding of R&D for digital technologies that are acquired by education and training systems. The pandemic triggered an almost threefold increase in education technology venture capital levels (HolonIQ, 2022[29]). This has been mostly led by a surge in European and United States investments in the area, whereas Asian countries led investment in education technologies worldwide before the pandemic. In addition, while education technology has traditionally supported formal education institutions, technologies, tools and services that directly target students, parents and workers have equally increased during the pandemic, triggering a rise in investment devoted to consumer-focused education products (HolonIQ, 2020[21]).

At the same time, education technology venture capital funding in European countries (14% of global education technology funding in 2021) remains lower than funding in other countries such as India (18%) or the United States (40%) (IDB and HolonIQ, 2021[30]). Overall, the size of the education technology industry remains moderate (for instance, in comparison to health), and education technology venture capital funding lags behind health technology and climate technology venture capital levels (HolonIQ, 2022[29]).

These figures prompt questions about the sufficiency of investment both on aggregate and relative terms (compared to other sectors and sometimes other countries). These questions are particularly relevant given the reliance of education systems on private actors in the development of tools, products and services for digital education, particularly in emergency contexts (Vincent-Lancrin, 2020[31]). A range of factors are likely to hold back investment and innovation in this sector, including regulatory frameworks in education systems, fragmented market demand for education technology, lack of incentives, insufficient access to capital and the geographic concentration of global venture capital investment. This should also be considered against the background of lagging digital innovation in Europe in general compared to the United States and a range of Asian countries (OECD ECOSCOPE, 2022[32]).

Another challenge for innovation in digital education technologies relates to the innovation-potential of venture capital. In European countries, only 2% (vs. 6% globally and 10% in East Asia) of the most promising start-ups in education technology[5] were founded during the pandemic[6] (HolonIQ, 2022[33]). Research evidence shows that venture capital tends to direct its investment focus towards less innovative start-ups during economic downturns (Howell et al., 2020[34]). During the pandemic, early-stage investments focusing on more innovative but also riskier start-ups declined relative to later-stage investments that targeted more mature education technology firms in order to support their rapid scale up (Dee, 2020[35]).

Promising approaches for establishing an equitable and innovative digital education infrastructure

Further invest in providing reliable connectivity for equitable digital learning opportunities

Beyond overarching policies to promote and facilitate broadband deployment and foster competition between providers, OECD countries have implemented policies to bring connectivity in areas not catered by markets including:

- co-ordinating, committing and bundling demand in rural areas;
- supporting public private partnership (PPP) initiatives; public funding to market players to expand connectivity in rural/remote areas through reverse auctions;
- supporting open access municipal and community-led networks and;

- providing “last mile” connectivity in rural and remote areas using technologies with less fixed costs such as fixed wireless access and including coverage obligations in auctions (OECD, 2021[36]) (OECD, 2021[37]).

In addition to policies targeting connectivity for all, governments have also worked on addressing poor internet connection in education institutions, by providing funding for broadband access and supporting access to fast and reliable internet connection in schools located in areas unlikely to benefit from commercial investment:

- In **Germany**, the Grey Spots Funding Programme has provided support for broadband roll-out in areas where commercial roll-out was not economically efficient (Federal Ministry for Digital And Transport, 2021[38]). The funds cover 50 to 70% of the costs of the gigabit roll-out and federal states also contribute to covering the costs. In 2021, the eligibility conditions for the Grey Spots Funding Programme were eased by adjusting the download bandwidth threshold for eligibility. A range of institutions, including schools, became eligible for funding, provided they did not benefit already from a very high-quality Internet connection.
- Through its digital centres initiative, **Colombia** invests an equivalent of USD 500 million to provide internet connection for learners in remove areas. Since 2020, the project has led to the creation of nearly six thousand digital centres - mainly based in public schools – which provide 24 hours internet access to rural communities (Ministry of Information Technologies and Communications of Colombia, 2023[39]).
- In the **United Kingdom**, the Rural Gigabit Connectivity Programme targets the delivery of gigabit connectivity in locations unlikely to be covered by commercial investment (DCMS, 2020[40]). The programme rests on two approaches. The Hub model approach identifies eligible public buildings and upgrades their connectivity, thereby enhancing its public service and potentially making the surrounding area more viable for commercial investment. A Rural Voucher approach targets the hardest to reach rural areas which can apply for a voucher in order to accelerate access to gigabit-capable connectivity. The Rural Gigabit Connectivity Scheme has also been used to identify schools (considered as hubs) in need of fibre connection and unlikely to benefit from it through commercial deployment.
- In the **United States**, the Federal Communications Commission E-Rate program has provided discounts to schools and libraries to support their access to affordable broadband services (Federal Communications Commission, 2022[41]). Schools can apply individually or through a consortium, to receive two categories of services: i) telecommunications, telecommunications services and Internet access and ii) internal connections, basic maintenance of internal connections and management of internal broadband services.

Other policy approaches and programmes increasingly focus on alternative solutions to bring connectivity to learners in areas without broadband and/or limited cell service. Indeed, while wired, wireless, fixed and mobile technologies can support the delivery of broadband connectivity, none of these technologies represents in itself the most appropriate option for all low-density and remote areas (OECD, 2021[42]). Prescribing specific technology solutions for bridging connectivity gaps in these areas may be less effective than maintaining an open approach to innovations and supporting technologies with growth potential in areas still reliant on legacy networks (OECD, 2021[42]). A range of programmes have leveraged or piloted the use of a mix of technologies to provide connectivity for learners or schools in very remote locations:

- As part of the Rural Access Gap program, the **New South Wales** government in **Australia** is investing in the infrastructure upgrade of rural and remote schools, in order to limit their dependence on satellite Internet and to close connectivity gaps with schools in urban areas. Schools in very remote areas benefit from upgrades through alternative technology, such as complex radio solutions coupled with buried and overhead fibre optic cable connections (NSW Government, 2022[43]).

- The **Massachusetts** Department of Elementary and Secondary Education (**United States**) established a partnership with a wireless network operator and a public school district to identify novel connectivity solutions for learners in rural areas lacking broadband access and having almost no cell service available. The Rural Internet Pilot Program showed that a mix of user-friendly tools that were easy to set up and deploy, and involved relatively low costs, provided effective solutions for the majority of households lacking Internet access (Massachusetts Department of Elementary and Secondary Education, 2021[44]).
- Also in the **United States**, the Coachella Valley Unified School District, which has a large proportion of students underneath the poverty line, equipped its school buses with solar powered WiFi-routers. Not only do these buses allow students to access the Internet during transit, once out of service the buses are also parked in underserved communities to provide broadband coverage.

Efforts have also focused on broadening off-site connectivity for learners. During the COVID-19 pandemic, countries have supported families who lack Internet access and data package subscriptions to ensure connectivity for learners of different backgrounds (Vincent-Lancrin, Cobo Romaní and Reimers, 2022[22]). In almost half of the countries covered by an OECD/UNESCO-UIS/UNICEF/World Bank Special Survey on COVID-19, measures targeting populations at risk of exclusion from distance education platforms included agreements with Global System for Mobile Communications operators/Internet firms to remove Internet access barriers (OECD, 2021[45]).

To keep track of inequality in access for students, policies can mandate or co-operate with education institutions to keep detailed registration data to help identify and support at-risk students, including those from lower socio-economic backgrounds and/or those living in poor broadband coverage areas. Policies can also support institutions providing support for students with poor access. For instance, in **New Zealand**, the Ministry of Education is providing guidance on how schools can become “Digital Hubs” that provide broadband access to their communities, and runs a number of pilots in co-operation with telecommunication companies, schools and community trusts to co-create solutions for students lacking Internet access (Ministry of Education, 2021[46]).

Higher education institutions in general are less likely to be located in areas with limited Internet access, compared to schools. The large capacity already installed to satisfy the links between higher education and research institutions to the NREN backbone network[7] makes it in principle possible for schools and VET institutions to benefit from the existing installed capacity. About half of NRENs in Europe can also connect schools and in fact schools were the fastest growing type of user for NRENs in 2019-2020 (Géant, 2022[47]). Schools and VET institutions are more likely to use NRENs for their connectivity needs in countries where NRENs dominate connectivity provision for higher education and research, which also coincides with cases where NRENs are mostly publicly funded (Géant, 2020[27]).

However, higher education institutions and policy makers still need to tackle digital divides in the home environment of their students. In some cases, as, for example, in the Community College of Aurora in the **United States**, higher education institutions are liaising with local leaders and community stakeholders, in order to encourage greater focus on improvements to the local digital infrastructure, and therefore improve the opportunities for students to access connectivity and other digital technologies off-campus (Pressley, 2022[48]).

Ensure sufficient and equitable access to quality digital equipment and tools

Bridge digital equipment gaps in education institutions

While the pandemic has shifted the focus of debates on digital equipment to private households, education systems have largely returned to in-person teaching, bringing renewed focus to digital equipment on the premises of education institutions. In this context, the disparities in digital equipment between education institutions which re-enforce access gaps between socio-economic groups and were highlighted in previous sections become once again critical. This calls for further investments to bridge gaps in digital infrastructure access but also to ensure the adequacy and quality of digital equipment overall. In fact, several countries have made significant investments in digital equipment over recent years with the intention to improve digital facilities for disadvantaged education institutions and students.

- For instance, the ICT Grant scheme in **Ireland** allocates a total of EUR 200 million to schools to purchase digital equipment between 2021 and 2027. The funding is based on a flat rate lump sum and a per capita amount per student enrolled. To narrow digital divides, the scheme further includes adjusted per capita rates for special need schools and schools that are part of the government's "Delivering Equality of opportunity in Schools" Programme – a scheme targeting 1 194 schools in Ireland with a high concentration of students at risk of educational disadvantage (Department of Education Ireland, 2022[49]; Department of Education Ireland, 2022[50]).
- Also in **Ireland**, during the pandemic, the Government Laptop Loan scheme provided funding for students from priority target groups (such as students with socio-economic barriers, disabled students and first-time mature students) in further and higher education institutions to cover the cost of the institution buying a laptop and loaning them to students for the duration of the studies. The scheme has been continued into the post-pandemic period (Department of Further and Higher Education, 2020[51]).
- COVID-19 recovery strategies have in some countries included new investments into the digital infrastructure of higher education institutions. For instance, the **United Kingdom** committed GBP 200 million to improve physical and digital infrastructure in more than 180 further education colleges in 2020 (FE News, 2020[52]).

With the upward trend of ownership and use of end-user hardware in the home (OECD, 2022[53]), some education institutions have turned to a Bring Your Own Device (BYOD) strategy to bridge equipment gaps. BYOD policies vary significantly across schools in terms of the eligibility requirements for different devices: While some schools simply advise students to bring their own devices other "managed" BYOD programmes require students to lease or purchase specific recommended laptop models or tablets (Burns and Gottschalk, 2019[54]). This can in principle reduce institutions' capital outlay and simplify and enhance the user experience. However, not all students have adequate digital technology at their disposal. Even where students have access to digital devices at home the sharing of devices among family members, or inadequate device quality (e.g. battery life or incompatibility with specialist software) might render these devices unfit for use in school. In addition, BYOD as a substitute for institutional equipment only works if personal devices can interoperate with the main institutional systems. Personal devices might lack required safeguards leading to privacy and security issues (van der Vlies, 2020[55]).

Combining BYOD approaches with central provision of digital devices might be a promising step to address these concerns whilst leveraging existing privately owned tools:

- For instance, **New Zealand** has traditionally relied strongly on BYOD policies at schools, with 55% of schools already having implemented BYOD for students in 2018. However, despite the salience of BYOD policies, 86% of schools also maintain pooled devices to provide alternatives to students who lack access to adequate personal devices (IDC, 2018[56]). A further 36 000 devices were made available to high-priority learners during the COVID-19 pandemic (Dowden, 2022[57]).
- In **Greece**, a voucher scheme for IT equipment was targeted particularly to students from low-income families and teachers (Danieliené, 2020[58]). As part of the scheme, more than 665 000 vouchers were given out to teachers and disadvantaged students between the age of 4 and 24.
- Similarly, BYOD policies might be limited to certain parts of the student population. For instance, a school district from Cincinnati (**United States**) has required students in upper grades to bring their devices, whereas younger students benefitted from a 1:1 programme (Office of Educational Technology, 2017[59]). The district also provided devices (for school use only) to those students who lacked a personal device.

As access to personal devices is not universal, 1:1 learning initiatives seek to provide all students with access to digital devices. In recent years, these device policies have increasingly leveraged portable devices thus enabling students to use digital devices both in schools and at home. Plan Ceibal in **Uruguay** arguably represents the earliest and most extensive example of a 1:1 programme. Between 2006 and 2009, laptops and free of charge Internet access were provided to all students and teachers at public primary and lower secondary schools (Ceibal, n.d.[60]). Efforts in consecutive years concentrated on strengthening teachers' and institutions' capacities and promoting adequate pedagogies for digital education. Whilst Plan Ceibal is one of the first examples of a coherent, nation-wide 1:1 programme that reduced divides in access to digital equipment and supported the uptake of Internet services in households, the systematic distribution of digital devices to students has become increasingly common in many education systems (Díaz, Dodel and Menese, 2022[61]).

While students have often been the focus of digital devices distribution programmes, teachers' access to digital technologies should equally be ensured. Evidence on teachers' access to school computers connected to the Internet (and available for teachers) shows strong cross-country variability (OECD, 2020[62]). However, little is known on the extent to which teachers have access to quality digital equipment (and connectivity) at home. During the pandemic, more than two-thirds of countries covered by a special OECD/UIS/UNESCO/UNICEF/World Bank Survey, provided digital tools (e.g. PC, mobile devices) or free connectivity (e.g. vouchers for mobile broadband) to teachers (OECD, 2021[45]). Documenting teachers' access to quality digital equipment and supporting teachers who lack access to necessary digital tools is a key precondition for successful digital education.

Another potentially relevant area for policy intervention relates to the development and maintenance of databases of available education technology tools/services and their use. Collecting data on the diversity of digital tools and particularly software available for student learning has proven challenging, in light of fast technological advances in the field and the lack of measurement tools. Data on penetration of advanced technologies (e.g. AI-based education tools) across education systems is particularly limited. Finally, data on the types and quality of equipment that education systems and institutions have for students with special education needs remain generally absent, with the exception of anecdotal examples or case studies. Monitoring the availability of specialised equipment for students with special education needs is required to ensure all students can access the necessary and appropriate digital equipment and tools.

During the pandemic, partnerships between education institutions as well as between private companies and the public sphere proved essential in mobilising resources and finding technical solutions to deliver distance learning (Vincent-Lancrin, Cobo Romaní and Reimers, 2022[22]). Developing and supporting these collaborative efforts beyond the pandemic can continue to bridge inequalities in the access to digital equipment. For instance, partnerships between education institutions can provide a means for pooling resources for infrastructure in cases where single education institutions do not have the appropriate digital infrastructure individually. In higher education, several countries in Europe have developed framework agreements for HEIs to purchase equipment collectively, and some countries have established co-operative structures that promote collective digital planning and technology acquisition (OECD, 2023[63]). In addition, public-private partnerships can be established at different levels of the system, for the purpose of infrastructure provision, mobilisation of financial or human resources or the delivery of support by IT experts in schools or more generally. For instance, **Estonia** has built a long-standing co-operation with the private sector, developing e-services for education openly to enable the private sector to also bring its contribution and be involved from the early stages in the development of tools (Education Estonia, 2021[64]).

At the same time collaboration with the private sector raises a series of questions, which have become more salient in the context of the pandemic, most notably with respect to the protection of student data collected through digital tools or platforms (see Chapter 4).

Promote access to digital devices at home

Despite an increasing return to in-person teaching, the pandemic has irrevocably changed the character of learning, making online learning management systems, virtual learning environments and online communication between teachers, parents and students essential components. As these new ways of learning will continue to play a substantive role after the pandemic, it remains crucial to bridge gaps in access to digital devices at home.

Even before the pandemic, many national policies sought to provide students with portable devices for learning (Conrads et al., 2017[65]):

- The Yo Elijo Mi PC programme in **Chile**, the Home Access Programme in **England (United Kingdom)** or the EURO 200 programme in **Romania** are examples of government schemes that provided computers to students from socio-economically disadvantaged backgrounds, or supported them through grants or subsidies in acquiring a device (Bulman and Fairlie, 2016[66]; Escueta et al., 2017[67]).
- Though less common, the pandemic has also triggered the launch of some programmes to provide access to digital devices for higher education students. For instance, **Ireland** offered a one-off EUR 17 million COVID-19 Grant to support disadvantaged higher education students in accessing digital devices and an additional EUR 10 million for access supports (Government of Ireland, 2020[68]).

Co-operations with the private sector have also proved useful in bridging access to digital equipment for learning. During the pandemic, central governments have worked with a range of stakeholders (e.g. schools, municipalities, statistics institutes) and private sector actors (e.g. EdTech companies, non-profit organisations, telecom firms) in collective efforts to address inequalities in students' access to digital equipment and tools (Vincent-Lancrin, Cobo Romaní and Reimers, 2022[22]). For instance, in **Korea**, the Ministry of Education co-operated with a range of stakeholders (e.g. private companies, local governments, Statistics Institute) to provide digital devices (and subsidised Internet subscription fees) to socio-economically disadvantaged students. In a range of countries, local authorities, private organisations or schools also played an important role in bridging equipment gaps at home (OECD, 2021[45]).

Ensure continuing efforts to build and maintain digital infrastructure in education in line with latest technological developments

Providing an enabling infrastructure for digital education is not a one-time effort. On the one hand, existing digital equipment requires continuous maintenance to remain functional. As new software or tools enter education institutions, upgrades of existing digital infrastructure might also become necessary to meet higher connectivity or computing capacity requirements. On the other hand, advances in digital technologies might provide the basis for new types of uses of digital tools in education (e.g. AI or blockchain). Some countries already provide examples for frontier uses of digital technologies education systems:

- In the **United Kingdom**, the Joint Information Systems Committee (JISC) launched a new national centre for AI in tertiary education in 2021 with the aim of delivering AI solutions to colleges and universities.
- In **Greece**, funding from the National Recovery and Resilience Plan was used to purchase 177 000 robotics kits for children between the ages of 4 and 15 (Kathimerini, 2022[69]).
- **Korea** marks an early example of introducing advanced technologies in its education system. Korea has progressively introduced AI in education since 2018, expanded software education in primary and middle schools, opened AI pilot schools and designated high schools to develop AI-based models for education (OECD, 2021[70]).

As discussed previously, not all uses of digital technologies succeed in improving learning outcomes and some uses of advanced technologies come with considerable ethical concerns. While new digital technologies should thus not be blindly adopted, performing horizon scanning and taking stock of technological developments is key to ensure that education systems make optimal use of digital technologies to enhance learning outcomes.

Boost investment and innovation in digital education technologies through a co-ordinated and multi-dimensional policy approach

Governments play a key role in providing the enabling conditions for investment and innovation in digital education technologies, either by supporting new firms to start and grow, or by providing targeted support to address the challenges faced by existing firms. Such policies can be crucial particularly in European countries that are currently lagging behind in technology creation for education systems compared to other countries (e.g. the United States). However, boosting digital innovation in education usually goes beyond the realm of education policy. Thus, a broader policy spectrum including small and medium-sized enterprises (SME) and entrepreneurship policies as well as structural factors such as insolvency regimes are relevant for fostering digital innovation. Broader policy approaches to foster innovation within the EdTech sector might include: i) targeting regulatory burdens for start-ups, ii) promoting diversified financing options for new entrants, iii) mobilising the private and public sector to support R&D for digital innovation, iv) incentivising innovation through tax-based credits and v) policy experimentation (OECD, 2020[71]).

While boosting innovation requires a multi-dimensional response, education authorities can support the creation of background conditions conducive to innovation in education technology. For instance, ensuring universal access to connectivity and appropriate equipment in education institutions and building the capacity to harness its potential, supports demand for innovative digital education technologies, and thereby creates incentives for research and investment in the sector. Several countries have launched specific support measures for the EdTech sector. These include support to access finance and investment, innovation funds and grants for digital education technologies development, support for education technology incubators or accelerators, and visa classes to attract technology specialists from abroad. Through these means governments can assist the development of sustainable and transformational digital technologies, tools and services where it requires long-term, higher-risk research that firms might otherwise be reluctant to invest in (OECD, 2017[72]).

There are several examples of countries or cities that have provided an array of public support measures to develop and sustain a dynamic EdTech sector:

- The Helsinki Education Hub in **Finland** provides support for EdTech entrepreneurship and new business including: support for international start-up businesses willing to enter the City of Helsinki, pre-incubator services (e.g. coaching to early-stage start-ups), access to the EdTech Incubator Helsinki programme and support for businesses seeking to enter international markets (Helsinki Education Hub, 2022[73]). The Hub rests on the close collaboration of the Economic Development Unit and the Education Division of the City of Helsinki and is currently financed by the City of Helsinki Innovation Fund. It benefits from co-operation with a range of partners including universities, private sector companies focused on digital technologies, the Finnish EdTech industry association, etc. (NewCo Helsinki, 2021[74]).
- In the **United Kingdom**, as part of the EdTech innovation programme built in partnership by the Department for Education and the National Endowment for Science, Technology and the Arts innovation foundation, the EdTech Innovation fund provided grants of more than GBP 1.3 million in total to 15 EdTech organisations between 2019 and 2021 (NESTA, 2022[75]). The grants were targeted at organisations working on technologies related to formative assessment, parental engagement, essay marking and timetabling to support their improvement, expand their reach and enhance the evidence base. In addition, the EdTech R&D programme funded and tested

improvements to adapt a range of education technology products to the shift to remote learning caused by the COVID-19 pandemic (NESTA, 2022[75]).

- In **France**, the Ministry of Education provides financial supports to eligible digital tools and digital learning content providers through its Édu-up initiative. Projects that propose a solution in the field of digital education resources can apply for grants up to EUR 70 000 (Ministère de l'Éducation nationale, 2023[76]).

Efforts can also focus on encouraging private investments in education technology development. Designing incentives for the private sector to invest in innovation for education requires understanding the structure and dynamism of the education technology market (World Bank, 2020[77]). While venture capital investments in education technologies have grown substantially in the last decade, the pandemic and previous economic downturns have shown that the most innovative education technologies do not always attract the largest investments (Dee, 2020[35]). Strategies to maximise returns on investment, based on scaling up rapidly by attracting a large user base, may lead firms and investments to favour existing or familiar technologies rather than more innovative and hence, potentially riskier, technologies (Reich, 2020[78]). Partnerships among diverse stakeholders can incentivise greater risk-taking in private technology investments. For instance, support for partnerships between start-ups, universities, industry, and government can facilitate business development and innovation by providing start-ups with opportunities for funding as well as equipment to test tools, services or products (OECD, 2019[79]).

Governments should also aim for better monitoring investment and developments in the EdTech industry. Currently, most evidence on the scale of the global digital education industry, the types of technologies that attract investment and the geographic distribution of investments stems from the private sector. The development of a more comprehensive monitoring infrastructure is required to gain a better understanding of the dynamics of the EdTech industry and of the market for education technology specifically, including the presence of potential market failures (Vincent-Lancrin, Cobo Romaní and Reimers, 2022[22]). Such an infrastructure would in turn allow better targeting of innovation-related policies for digital education technologies. Chapter 9 analyses more in depth the design of a monitoring and evaluation infrastructure for digital education.

Beyond promoting innovation of digital technologies, government action might also serve to steer education technology markets to better serve desired goals for education. Education technologies are often purchased with public resources, are accessed by vulnerable users and have a significant influence over learning outcomes. Governments should thus have strong interests in guaranteeing that education technologies provided on private markets serve the public good. In this context, some countries – such as **Estonia** – have launched extensive public-private partnerships to allow collaboration between companies and the public sector to realise the full potential of digital technologies for education (Education Estonia, 2021[80]).

Governments also need to encourage better collaboration between education and training institutions and developers of education technology to ensure that new tools and equipment actually match the needs of and contexts in which education institutions, educators and learners evolve (as discussed in Chapter 3). In particular, educators' involvement in the development of digital education technologies during the R&D process is crucial to ensure digital technologies are designed for users and with the needs of the learning ecosystem in mind.

Key messages

Education systems across the OECD and EU have seen large investments in digital infrastructure over the past decade. However, this chapter highlights significant gaps both with respect to the equitable access to digital infrastructure and the quality of digital infrastructure overall. In particular, socio-economically disadvantaged education institutions are less likely to benefit from an enabling digital infrastructure including high-speed Internet and functional digital devices. Overall, education institutions report significant challenges in ensuring the quality of digital equipment and advanced technologies (e.g. blockchain or AI) have only found limited use in most education systems.

The COVID-19 pandemic has further elevated equity concerns regarding digital infrastructure as students have become increasingly reliant on the availability of high-quality digital equipment and high-speed Internet at home. As students rely on digital tools for learning at home even after the pandemic, these issues remain relevant. This chapter thus highlights a range of initiatives that countries have taken to bridge connectivity gaps and supply digital devices to disadvantaged learners.

Going forward, the extent to which education provision can benefit from digital technologies heavily depends on innovative forces in private EdTech markets. Currently, many countries – particularly in Europe – face low levels of private investment in digital technologies and the pandemic has likely contributed to greater risk-adversity in EdTech investments. Governments can influence the dynamics of EdTech markets both through regulation and investment. This chapter thus presents promising initiatives taken in OECD and EU member countries – including public-private partnerships or EdTech incubators – which aim to strengthen the innovative capacity of EdTech markets and steer them to better cater education needs.

References

5G Observatory (2022), *Report: 5G coverage doubles in Europe*, https://5gobservatory.eu/report-5g-coverage-doubles-in-europe/ (accessed on march 2022). [7]

Bergman, P. (2019), "Nudging Technology Use: Descriptive and Experimental Evidence from School Information Systems", *Education Finance and Policy*, pp. 1-43, https://doi.org/10.1162/edfp_a_00291. [25]

Bulman, G. and R. Fairlie (2016), "Technology and Education: Computers, Software, and the Internet", in *Handbook of the Economics of Education*, https://doi.org/10.1016/B978-0-444-63459-7.00005-1. [66]

Burns, T. and F. Gottschalk (eds.) (2019), *Educating 21st Century Children: Emotional Well-being in the Digital Age*, Educational Research and Innovation, OECD Publishing, Paris, https://doi.org/10.1787/b7f33425-en. [54]

Ceibal (n.d.), *Ceibal*, https://ceibal.edu.uy/en/about-us/ (accessed on 6 March 2023). [60]

Conrads, J. et al. (2017), *Digital Education Policies in Europe and Beyond: : Key Design Principles for More Effective Policies*, Redecker, C., P. Kampylis, M. Bacigalupo, Y. Punie (ed.), EUR 29000 EN, Publications Office of the European Union, Luxembourg, https://doi.org/10.2760/462941. [65]

Cullinan, J. et al. (2021), "The disconnected: COVID-19 and disparities in access to quality broadband for higher education students", *International Journal of Educational Technology in Higher Education*, Vol. 18/1, https://doi.org/10.1186/s41239-021-00262-1. [9]

Danieliené, I. (2020), *560,000 low-income students to benefit from IT subsidy*, https://www.navinvestgreece.com/post/560-000-low-income-students-to-benefit-from-it-subsidy (accessed on 3 April 2023). [58]

DCMS (2020), *Rural Gigabit Connectivity Programme*. [40]

Dee, T. (2020), *VCs Are Pouring Money Into the Wrong Education Startups | WIRED*, WIRED, https://www.wired.com/story/vcs-are-pouring-money-into-the-wrong-education-startups/ (accessed on 7 April 2022). [35]

Department of Education Ireland (2022), *Grant Scheme for ICT Infrastructure – 2021/2022 School Year*, https://www.gov.ie/en/circular/e1f8e-grant-scheme-for-ict-infrastructure-20212022-school-year/ (accessed on 30 January 2023). [49]

Department of Education Ireland (2022), *Minister Foley announces €32 million major expansion of the DEIS programme incorporating 310 new schools*, https://www.gov.ie/en/press-release/71054-minister-foley-announces-32-million-major-expansion-of-the-deis-programme-incorporating-310-new-schools/ (accessed on 30 January 2023). [50]

Department of Further and Higher Education, R. (2020), *Minister Harris announces 17,000 laptops ordered to assist students with online and blended learning*, https://www.gov.ie/en/press-release/7143d-minister-harris-announces-17000-laptops-ordered-to-assist-students-with-online-and-blended-learning/ (accessed on 13 April 2023). [51]

Department of Further and Higher Education, R. (ed.) (2020), *Minister Harris announces 17,000 laptops ordered to assist students with online and blended learning*, https://www.gov.ie/en/press-release/7143d-minister-harris-announces-17000-laptops-ordered-to-assist-students-with-online-and-blended-learning/# (accessed on March 2022). [68]

Dettling, L., S. Goodman and J. Smith (2018), "Every Little Bit Counts: The Impact of High-Speed Internet on the Transition to College", *The Review of Economics and Statistics*, Vol. 100/2, pp. 260-273, https://doi.org/10.1162/rest_a_00712. [3]

Díaz, C., M. Dodel and P. Menese (2022), "Can one laptop per child reduce digital inequalities? ICT household access patterns under Plan Ceibal", *Telecommunications Policy*, Vol. 46/9, p. 102406, https://doi.org/10.1016/J.TELPOL.2022.102406. [61]

Dowden, A. (2022), "Provision of Internet Connectivity and Devices to Learners | Evaluation Report", https://www.educationcounts.govt.nz/__data/assets/pdf_file/0007/214468/Full-Report-Evaluation-of-Provision-of-Connectivity-and-Devices-A-Covid-19-Response.pdf (accessed on 28 February 2023). [57]

Dwivedi, Y. et al. (2023), ""So what if ChatGPT wrote it?" Multidisciplinary perspectives on opportunities, challenges and implications of generative conversational AI for research, practice and policy", *International Journal of Information Management*, Vol. 71, p. 102642, https://doi.org/10.1016/J.IJINFOMGT.2023.102642. [24]

Education Estonia (2021), *Three ways public-private partnerships are transforming education. Insights from Estonia*, https://www.educationestonia.org/education-public-private-partnerships-in-estonia/ (accessed on 18 May 2022). [64]

Education Estonia (2021), *Three ways public-private partnerships are transforming education. Insights from Estonia - Education Estonia*, https://www.educationestonia.org/education-public-private-partnerships-in-estonia/ (accessed on 13 April 2023). [80]

Educause (2022), *2022 EDUCAUSE Horizon Report | Teaching and Learning Edition | EDUCAUSE*, https://library.educause.edu/resources/2022/4/2022-educause-horizon-report-teaching-and-learning-edition (accessed on 8 July 2022). [26]

Educause (ed.) (2021), *Student Experiences with Technology in the Pandemic*, https://library.educause.edu/resources/2021/4/student-experiences-with-technology-in-the-pandemic (accessed on March 2022). [19]

Escueta, M. and S. Holloway (2019), "Investment in Education Technology Across the Globe: Where Profit Meets Purpose", *ENTREPRENEURSHIP & POLICY WORKING PAPER SERIES*, Columbia School of International and Public Affairs. [28]

Escueta, M. et al. (2017), "Education Technology: An Evidence-Based Review", http://www.nber.org/papers/w23744. [67]

European Commission (2021), *Digital Economy and Society Index (DESI) 2021*, https://digital-strategy.ec.europa.eu/en/library/digital-economy-and-society-index-desi-2021 (accessed on 2022). [5]

European Commission (2019), *2nd Survey of Schools: ICT in Education - Objective 1: Benchmark progress in ICT in schools*, Luxembourg: Publications Office of the European Union, https://digital-strategy.ec.europa.eu/en/library/2nd-survey-schools-ict-education-0. [12]

FE News (2020), *More than 180 colleges receive share of £200 million to bring building and digital infrastructure up to date*, https://www.fenews.co.uk/fe-voices/more-than-180-colleges-receive-share-of-200-million-to-bring-building-and-digital-infrastructure-up-to-date/ (accessed on March 2022). [52]

Federal Communications Commission (2022), *E-Rate - Schools & Libraries USF Program*, https://www.fcc.gov/general/e-rate-schools-libraries-usf-program (accessed on 12 April 2022). [41]

Federal Ministry for Digital And Transport (2021), *Broadband funding by the Federal Government*, https://www.bmvi.de/EN/Topics/Digital-Matters/Broadband-Deployment/Broadband-Funding-Programme/broadband-funding-programme.html (accessed on 20 April 2022). [38]

Géant (2022), *NREN service portfolios*, https://compendiumdatabase.geant.org/reports/nrens_services (accessed on March 2022). [47]

Géant (2020), *Compendium of National Research and Education Networks in Europe - 2020*, https://about.geant.org/wp-content/uploads/2021/12/Compendium_FINAL2.pdf. [27]

Gonzales, A., J. McCrory Calarco and T. Lynch (2018), "Technology Problems and Student Achievement Gaps: A Validation and Extension of the Technology Maintenance Construct", *Communication Research*, Vol. 47/5, pp. 750-770, https://doi.org/10.1177/0093650218796366. [18]

Helsinki Education Hub (2022), *Home - Helsinki Education Hub*, https://educationhubhelsinki.fi/ (accessed on 13 April 2022). [73]

Holmes, W. et al. (2022), "Artificial Intelligence and Education: A critical view through the lens of human rights, democracy and the rule of law", http://book.coe.int (accessed on 7 April 2023). [23]

HolonIQ (2022), *2022 Global Education Outlook (extract)*, https://www.holoniq.com/notes/2022-global-education-outlook/ (accessed on 7 April 2022). [29]

HolonIQ (2022), *Global EdTech 1000 - 2021 Stats*, https://www.holoniq.com/notes/global-edtech-1000-2021-stats-and-2022-applications-open/ (accessed on 7 April 2022). [33]

HolonIQ (2020), *Global EdTech market to reach $404B by 2025 - 16.3% CAGR*, https://www.holoniq.com/notes/global-education-technology-market-to-reach-404b-by-2025/ (accessed on 10 August 2020). [21]

Holslin, P. (2021), *How to Reduce Zoom Data Usage*, https://www.satelliteinternet.com/resources/how-to-reduce-zoom-data-use/. [1]

Howell, S. et al. (2020), "How Resilient is Venture-Backed Innovation? Evidence from Four Decades of U.S. Patenting", https://doi.org/10.3386/W27150. [34]

IDB and HolonIQ (2021), *Education Technology in Latin America and the Caribbean*, https://publications.iadb.org/publications/english/document/Education-Technology-in-Latin-America-and-the-Caribbean.pdf (accessed on 12 April 2022). [30]

IDC (2018), *IDC Education Study: Digital Education in Schools*, https://www.education.govt.nz/assets/Uploads/IDC-Education-Study-June-2018-Summary-Survey-Results.pdf (accessed on 30 January 2023). [56]

Kathimerini (2022), *Robotics kits for children in Greek schools*, https://www.ekathimerini.com/economy/1177793/robotics-kits-for-children-in-greek-schools/ (accessed on 3 April 2023). [69]

Massachusetts Department of Elementary and Secondary Education (2021), "Sustaining Progress in Access and Equity: EdTech Strategic Planning Guide", https://www.doe.mass.edu/edtech/ (accessed on 17 May 2022). [44]

Ministère de l'Éducation nationale (2023), *Le dispositif Édu-up*, https://eduscol.education.fr/1603/le-dispositif-edu (accessed on 3 April 2023). [76]

Ministry of Education (2021), *Home internet access – Education in New Zealand*, https://www.education.govt.nz/school/digital-technology/your-schools-ict-network/enabling-home-internet-access-for-your-community/ (accessed on 17 May 2022). [46]

Ministry of Information Technologies and Communications of Colombia (2023), *Digital Centers*, https://www.mintic.gov.co/micrositios/centros_digitales/768/w3-channel.html. [39]

Montacute, Rebecca; Holt-White, Erica (2020), *University Access & Student Finance*, The Sutton Trust, https://www.suttontrust.com/wp-content/uploads/2020/05/COVID-19-and-Social-Mobility-Impact-Brief-2.pdf. [10]

Mosley, N. (2022), *What's the current state of the VLE market in UK higher education?*, https://www.neilmosley.com/blog/whats-the-current-state-of-the-vlelms-space-in-uk-higher-education (accessed on 19 May 2022). [16]

NESTA (2022), *Reflections on the EdTech Innovation Partnership*, https://www.nesta.org.uk/project-updates/reflections-edtech-innovation-partnership/ (accessed on 10 April 2022). [75]

NewCo Helsinki (2021), *Helsinki Education Hub – flywheel for EdTech Startups*, https://newcohelsinki.fi/en/news/helsinki-education-hub-flywheel-for-edtech-startups/ (accessed on 13 April 2022). [74]

NSW Government (2022), *Better connectivity to close digital divide*, https://education.nsw.gov.au/about-us/strategies-and-reports/schools-digital-strategy/projects-and-initiatives/fast-reliable-and-secure-connectivity (accessed on 13 April 2022). [43]

Observatorio Nacional 5G (2022), *European homes with fiber optics have tripled in the last five years*, https://on5g.es/en/european-homes-with-fiber-optics-have-tripled-in-the-last-five-years/ (accessed on 13 April 2023). [13]

OECD (2023), *Advancing Digital Maturity in Croatia's Higher Education System*, OECD Publishing, Paris, https://doi.org/10.1787/26169177. [63]

OECD (2022), *Access to computers from home*, https://data.oecd.org/ict/access-to-computers-from-home.htm (accessed on March 2022). [53]

OECD (2022), *broadband portal*, https://www.oecd.org/digital/broadband/broadband-statistics/ (accessed on March 2022). [6]

OECD (2022), *Mending the Education Divide: Getting Strong Teachers to the Schools That Need Them Most*, TALIS, OECD Publishing, Paris, https://doi.org/10.1787/92b75874-en. [15]

OECD (2021), *Bridging digital divides in G20 countries*, OECD Publishing, Paris, https://doi.org/10.1787/35c1d850-en. [36]

OECD (2021), *Delivering Quality Education and Health Care to All: Preparing Regions for Demographic Change*, OECD Rural Studies, OECD Publishing, Paris, https://www.oecd-ilibrary.org/docserver/83025c02-en.pdf?expires=1652780875&id=id&accname=ocid84004878&checksum=868DCFBDB8F867D6817415B60B6F64BA (accessed on 17 May 2022). [42]

OECD (2021), *Delivering Quality Education and Health Care to All: Preparing Regions for Demographic Change*, OECD Rural Studies, OECD Publishing, Paris, https://doi.org/10.1787/83025c02-en. [37]

OECD (2021), *Education Policy Outlook 2021: Shaping Responsive and Resilient Education in a Changing World*, OECD Publishing, Paris, https://doi.org/10.1787/75e40a16-en. [70]

OECD (2021), *The State of Higher Education: One Year into the COVID-19 Pandemic,*, OECD Publishing, Paris, https://www.oecd-ilibrary.org/docserver/83c41957-en.pdf?expires=1652952184&id=id&accname=ocid84004878&checksum=0C4D6A51EDC4A0BE8FF007D090163208 (accessed on 19 May 2022). [17]

OECD (2021), *The State of School Education: One Year into the COVID Pandemic*, OECD Publishing, Paris, https://www.oecd-ilibrary.org/docserver/201dde84-en.pdf?expires=1632997342&id=id&accname=guest&checksum=AB7A563077A4309BB5207DC1BF8D8508 (accessed on 30 September 2021). [45]

OECD (2020), *OECD Digital Economy Outlook 2020*, OECD Publishing, Paris, https://www.oecd-ilibrary.org/docserver/bb167041-en.pdf?expires=1649407912&id=id&accname=ocid84004878&checksum=622C667A00E953D9887D14298488AF4C (accessed on 8 April 2022). [71]

OECD (2020), *PISA 2018 Results (Volume V): Effective Policies, Successful Schools*, PISA, OECD Publishing, Paris, https://www.oecd-ilibrary.org/docserver/ca768d40-en.pdf?expires=1612200121&id=id&accname=guest&checksum=E54D5229D27FF6FE5BC6DD9C9F36F420 (accessed on 1 February 2021). [11]

OECD (2020), *PISA 2018 Results (Volume V): Effective Policies, Successful Schools*, PISA, OECD Publishing, Paris, https://doi.org/10.1787/ca768d40-en. [62]

OECD (2020), *PISA 2018 technical background*, https://doi.org/10.1787/1b045c06-en. [81]

OECD (2019), *2018 Database - PISA*, https://www.oecd.org/pisa/data/2018database/ (accessed on 13 April 2023). [8]

OECD (2019), *Going Digital: Shaping Policies, Improving Lives*, OECD Publishing, Paris, https://doi.org/10.1787/9789264312012-en. [79]

OECD (2018), *PISA 2018 Database*, https://www.oecd.org/pisa/data/2018database/. [14]

OECD (2017), *OECD Science, Technology and Industry Scoreboard 2017: The digital transformation*, OECD Publishing, Paris, https://doi.org/10.1787/9789264268821-en. [72]

OECD ECOSCOPE (2022), *How can Europe catch up on its digital backlog?*, https://oecdecoscope.blog/2022/05/17/how-can-europe-catch-up-on-its-digital-backlog/amp/ (accessed on 17 May 2022). [32]

Office for Students (2020), *'Digital poverty' risks leaving students behind*, https://www.officeforstudents.org.uk/news-blog-and-events/press-and-media/digital-poverty-risks-leaving-students-behind/ (accessed on March 2022). [20]

Office of Educational Technology (2017), *Building Technology Infrastructure for Learning Building Technology Infrastructure for Learning*, U.S. Department of Education, https://tech.ed.gov (accessed on 21 April 2022). [59]

Pressley, J. (2022), *Bridging the Digital Divide & Digital Equity Gap in Higher Ed | EdTech Magazine*, https://edtechmagazine.com/higher/article/2022/03/understanding-digital-equity-gap-and-bridging-digital-divide-higher-ed-perfcon (accessed on 13 April 2023). [48]

Reich, J. (2020), *Failure to disrupt : why technology alone can't transform education*, Harvard University Press. [78]

Sanchis-Guarner, R., J. Montalbán and F. Weinhardt (2021), "Home Broadband and Human Capital Formation", *SSRN Electronic Journal*, https://doi.org/10.2139/ssrn.3772087. [2]

Skinner, B. (2019), "Making the Connection: Broadband Access and Online Course Enrollment at Public Open Admissions Institutions", *Research in Higher Education*, Vol. 60/7, pp. 960-999, https://doi.org/10.1007/s11162-018-9539-6. [4]

van der Vlies, R. (2020), "Digital strategies in education across OECD countries: Exploring education policies on digital technologies", *OECD Education Working Papers*, No. 226, OECD Publishing, Paris, https://doi.org/10.1787/33dd4c26-en. [55]

Vincent-Lancrin, S. (2020), *Coronavirus and the future of learning: Towards a new EdTech industry?*, OECD Education and Skills Today, https://oecdedutoday.com/coronavirus-future-learning-new-edtech-industry/ (accessed on 6 August 2020). [31]

Vincent-Lancrin, S., C. Cobo Romaní and F. Reimers (eds.) (2022), *How Learning Continued during the COVID-19 Pandemic: Global Lessons from Initiatives to Support Learners and Teachers*, OECD Publishing, Paris, https://doi.org/10.1787/bbeca162-en. [22]

World Bank (2020), *Innovation Ecosystem Knowledge Pack*. [77]

Notes

[1] According to the PISA 2018 technical background, “advantaged and disadvantaged schools are defined in terms of the socio-economic profile of schools. All schools in each PISA participating education system are ranked according to their average PISA index of economic, social and cultural status (ESCS) and then divided into four groups with approximately an equal number of students (quarters). Schools in the bottom quarter are referred to as “socio-economically disadvantaged schools”; and schools in the top quarter are referred to as “socio-economically advantaged schools” (OECD, 2020[81]).

[2] The percentage of variance in student performance explained by the PISA index of economic, social and cultural status was used as measure of inequity in performance. In a first step, the correlation coefficients between measures of material resources and inequity were computed. In a second step, the sign of the correlation coefficients was reversed (i.e., multiplied by -1) to simplify reporting (i.e., report correlation with equity instead of with inequity). (OECD, 2020[62]).

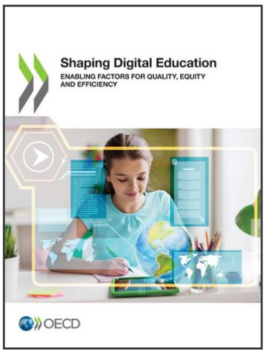
[3] Rather than physical infrastructure (e.g. building, grounds).

[4] The cluster analysis performed to derive the “digitally equipped and connected schools” profiles was based on schools’ equipment provision, proportion of fully operational equipment, Internet speed at school and type of Internet access and indicators of access to digital content (European Commission, 2019[12]).

[5] HolonIQ (2022[33]) identifies promising start-ups based on a range of criteria including the attractiveness of the market in which they operate, the quality, uniqueness and demonstrated impact of their product, the expertise of the team, the financial health of the company and positive changes in the size of the company over time.

[6] These figures exclude the Baltic countries for which a separate share is computed and represents 12%.

[7] Backbone networks interconnect networks by providing a path for the exchange of information between different LANs or subnetworks.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