ED/GEMR/MRT/2023/T1/1

Background paper prepared for
the 2023 Global Education Monitoring Report

Technology and education

Technology in education

MARY BURNS

2021

ABSTRACT

This think piece was commissioned by the Global Education Monitoring Report (GEM Report) Team to provide initial conceptual framing for the 2023 GEM Report, which focuses on information and communications technologies in education, or educational technology. The topics in this think piece were proposed by the GEM Report Team. As much as space permits, the think piece takes both a close up and wide-angle approach to technology.

The think piece focuses, as much as possible, on research outlining the educational benefits of technology and organises educational technology along three axes: (1) technology as a learning tool; (2) technology to deliver learning; and (3) technology to support learning, outlining the uses, benefits, challenges, and additional areas for research associated with each. It discusses the technology tools associated with each category and poses additional research questions that the GEM Reporting Team may wish to explore for the Global Education Monitoring Report.

ABOUT THE AUTHOR

Mary Burns is a senior technology and teacher professional development specialist based at Education Development Center in Waltham, MA (USA). Since 1997, she has designed, delivered, researched, and evaluated technology-based instructional and teacher professional development programmes across the globe, in the Global North and South, working directly with teacher educators, teachers and students. She advises governments, bilateral and multilateral donor agencies, universities, and school districts on using technology to improve teaching and learning and has developed technology strategies for school districts, states, and Ministries of Education. She has received awards for teaching with technology, for designing technology-based teacher professional development curricula, and for research on technology. Burns has published books, book chapters, peer-reviewed journal articles, and online articles about educational technology.

ACKNOWLEDGEMENTS

The author wishes to thank the following: Barbara Parmenter; Curt Newton (OpenCourseWare; Catherine Casserly (Casserly Consulting; formerly Hewlett Foundation and Creative Commons CEO); Angela DeBarger (William and Flora Hewlett Foundation); Anna Maria Raad (Aprendo en Casa, Chile); Beatrice Avalos (Universidad de Chile); Shannon Knapp (North Syracuse [New York] School District); Maggie Pickett (Centre for Applied Spatial Technologies, Inc.); Susie Blackstein-Adler (Bridges, Canada); Helen Boyle, Daniel Lavan, and Patricia Konarski (Education Development Center); Emily Morris (American University); Richard Culatta and Mindy Frisbee (International Society for Technology in Education); and Cable Green (Creative Commons) for their support, insights, and suggestions. Thanks to Manos Antoninis, Francesa Endrizzi, and Daniel April of GEM for their careful review. A final thanks you to Arjana Blazic (Teacher trainer, Croatia); Torrey Trust (University of Massachusetts, Amherst, Massachusetts); Caitlin Tucker (Blended learning author, United States); and Lauren McIntyre (Amphitheatre Public Schools, Tucson, Arizona) for permission to use their resources, which are embedded as links in this think piece.

The comments and conceptualisations presented here represent those of the author and should not be attributed to any individual or organisation mentioned above, the GEM Report Team, or UNESCO.

TABLE OF CONTENTS

LIST OF ACRONYMS

acceptable use policy	AUP
Adaptive Learning Game Design	ALGAE
alternative and augmentative communication	AAC
Annual Status of Education Report	ASER
artificial intelligence	AI
artificial intelligence in education	AIED
attention-deficit/hyperactivity disorder	ADHD
automated voice message	AVM
bring your own device	BYOD
computer-aided instruction	CAI
Children’s Online Privacy Protection Act	COPPA
computer-aided learning	CAL
computer adaptive test/testing	CAT
Conectividad Educativa de Informática Básica para el Aprendizaje en Línea	CEIBAL
coronavirus disease	COVID
Corporation for Public Broadcasting	CPB
Department of Basic Education	DBE
Digital Accessible Information System	DAISY
Dynamic Indicators of Basic Early Learning	DIBELS®
Education Development Center	EDC
education management information system	EMIS
extensible markup language	XML
The Family Education Rights and Privacy Act	FERPA
Foreign, Commonwealth and Development Office	FCDO
General Certificate of Secondary Education	GCSE
General Data Protection Regulation	*GDPR*
Geographic Information System	GIS
Global Education Coalition	GEC
Global Education Monitoring Report	GEM
Global System for Mobile Communications	GSMA
Generative Pre-Trained Transformer 3	GPT3
Indira Gandhi National Open University	IGNOU
Individuals with Disabilities Education Act	IDEA
information and communications technology(ies)	ICTs
institutional review board	IRB
integrated learning systems	ILS
intelligent tutoring system(s)	ITS
interactive audio instruction	IAI
interactive radio instruction	IRI
interactive voice response	IVR
internally displaced person/people	IDP/IDPs
International Rescue Committee	IRC
internet protocol	IP
Job Access with Speech	JAWS
lesbian, gay, bisexual, transgender, queer, and other identities	LGBTQ+
low and middle income countries	LMIC
Maine Learning Technology Initiative	MLTI

Massachusetts Institute of Technology	MIT
National Instructional Materials Accessibility Standard	NIMAS
Non-Fungible Token	NFT
One Laptop per Child	OLPC
Open CourseWare	OCW
Open Education Resources	OER
open-source software	OSS
optical character recognition	OCR
Organisation for Economic Co-operation and Development	OECD
Organization of American States	OAS
personally identifiable information	PII
Programme for International Student Assessment	PISA
randomised control trial	RCT
Research Triangle Incorporated	RTI
Scholastic Aptitude Test	SAT
science, technology, engineering and mathematics	STEM
secure digital card	SD
short message service	SMS
social and emotional learning	SEL
standard deviation	SD
standard mean difference	SMD
student information system	SIS
Sustainable Development Goals	SDG
Teacher Education in Sub-Saharan Africa	TESSA
Teaching and Learning International Survey	TALIS
Unique Learning Technology Identifier	ULTID
United Nations Children's Emergency Fund	UNICEF
United Nations High Commissioner for Refugees	UNHCR
Universal Product Code	UPC
Web Content Accessibility Guidelines	WCAG

LIST OF TABLES AND FIGURES

SECTION I: OVERVIEW

1.1. THE NOISE AND THE SIGNAL OF EDUCATIONAL TECHNOLOGY

Few innovations have generated such excitement and idealism—and such disappointment and cynicism—as information and communication technology in education. Four decades after the introduction of computers in schools; three decades after the first 1:1 computing programme was launched in Australia; two decades after the appearance of virtual schools; roughly a decade after the dawn of tablets; and now, as parts of the globe tentatively and anxiously emerge from the worst pandemic in over a century, the noise around 'educational technology' is as cacophonous and contradictory as ever. To wit: Computers are cast as an expensive boondoggle that do nothing to aid learning, yet tablets proliferate across schools in Asia and Sub-Saharan Africa. Online learning promises equity of access to learning for all the world's students, yet during COVID 19, online learning generally benefited the 'easiest to reach'—students from wealthy families and communities in wealthy countries—thus exacerbating educational inequities. Educational technology can help students improve reading, math, and writing skills, yet it has failed to deliver consistent learning results. 'Successful 'technology interventions often fail to reproduce similar results in different—or even similar—contexts.

> It is often difficult, if not impossible, for educators to find meaningful, consistent, reliable information on educational technology (ed tech) products. While reviews can be found across numerous educational and vendor websites, they are often single reviews that may not evaluate different versions of the same product.
>
> The International Society of Technology in Education (ISTE) has embarked upon a process of standardising and making reviews of ed tech products more accessible. Vendors and developers can register their technology products on ISTE's open access Learning Technology Directory, where the product is assigned a Unique Learning Technology Identifier (ULTID). This ID— similar to a Universal Product Code found on items purchased in a store or online—becomes the unique identifier attached to a particular ed tech product so that all ed tech stakeholders can access consistent information on each product (R. Culatta, personal interview, June 2021; M. Frisbee, personal interview, July 2021).

Box 1: *Evaluating educational technology products*

The research base has traditionally done little to quiet this clamour. Evidence around the effectiveness of technology for improved learning can be described as falling into one of three categories: *success* (sometimes); *failure* (broadly), or no *significant difference* (generally) (Tamim et al., 2011; Spezia, 2010; McEwan, 2015; Kizilcec et al., 2020; Angrist and Lavy, 2002; Fuchs and Wößmann, 2005; Pedró, 2012; Burns, 2013a).

Competing narratives and inconsistent research findings on educational technology raise genuine concerns, but the picture they paint is incomplete. Amidst the noise around educational technology, the signal has grown stronger over the last few years, and our understanding of technology has begun to come into clearer focus. This is due to multiple factors:

- The maturation and increased prevalence of educational technology, thus allowing for studies with adequate power and longitudinal data
- The accumulation of years of intensive experiences using a variety of technologies for a variety of educational purposes, thereby contributing to shared and applied knowledge about 'best practices'
- Increasing demands for rigorous, evidence-based research by donors, governments, and educational organisations, culminating in the creation of entities such as the EdTech Hub[1] and the open access Learning Technology Directory by the International Society of Technology in Education (ISTE; described in Box 1).

1 The EdTech Hub is a global non-profit research partnership, sponsored by the United Kingdom's Foreign, Commonwealth and Development Office (FCDO), the Bill & Melinda Gates Foundation, and the World Bank, to study educational technology to provide policymakers and donors with evidence on what works.

These developments should continue to paint a fuller picture of the kinds of accommodations and conditions that must be in place for technology's promise and potential to be fulfilled. And they should help to further document technology's diffuse educational benefits as well the many challenges associated with its effective implementation and integration for improved teaching and learning.

Here is what we *do* know about educational technology: We know that that in terms of learning, students are more likely to learn with technology than without it, particularly at-risk learners (Tamim et al., 2011; Bebell and Kay, 2010; Silvernail and MLTI Research and Evaluation Team, 2011; Major and Francis, 2020; Darling-Hammond, Zielezinski and Goldman, 2014). We know that if students in the Global South cannot use technology as frequently and in similar ways as their peers in wealthy countries, they will be left behind in terms of educational and professional opportunities (MasterCard Foundation, 2020).

Although some research (World Bank Group, 2020) cautions that educational technology (ed tech) is not a smart buy for governments, such admonitions have done little to deter private investors seeking lucrative financial returns. Venture capital investment in ed tech more than doubled, from US$7 billion in 2019 to $16 billion in 2020 (The Economist, 2021c). Much of this growth was driven by the COVID-19 pandemic (Paykamian, 2021; Pelletier et al., 2021). In just the first few months of the remote schooling response to 2020 pandemic-related school closures, Google Classrooms saw an increase of 100 million new subscribers (DeVynck and Bergen, 2020).

As of July 2021, there were an estimated 27 private ed tech companies with a valuation of over US$1 billion. This number is far lower than in other sectors, but almost triple the amount from 2008 (Holon IQ, 2021).

While the U.S. is still the largest investor in ed tech, the greatest growth in educational technology investment is in Asia. Eighty percent of the US$16.2 billion invested in ed tech globally in 2020 was driven by Asian countries, primarily China (by far) and India. Much of this investment has been focused tutoring, exam preparation, and personalised learning programs (EdSurge, 2020; The Economist, 2021c).

Box 2: *Worldwide growth in investment in educational technology*

We know also that technology's problems and successes are rarely due to technology alone—they are more often created by decisions and practices that are political, educational, financial, human, and institutional. Many educational systems attempt to use technology to overcome existing constraints in the education system (De Melo et al., 2014). Yet we know that technology *ipso facto* cannot fix poor teaching and modernise outdated curricula that emphasise lower order thinking skills and the assessments that measure them.

However, technology can be an important component of educational improvement when it is part of a carefully designed and implemented programme of whole system reform (Culp, Honey and Mandinach, 2005). We do know that for many of the world's teachers and students, the lack of access to a cellular network, an internet signal, or a digital device has been tantamount to a lack of access to education. And we know that technology, because of its ability to scale, can make attainment of Sustainable Development Goal 4 (SDG4)—'ensur(ing) inclusive and equitable quality education and promot(ing) lifelong learning opportunities for all '(United Nations Department of Economic and Social Affairs, 2021)—far more possible than it would be without technology.

As this think piece will repeatedly emphasise, educational technology is a highly complex intervention. As such, more than many interventions, it demands much from the education systems that seek to deploy it:

- It demands access to infrastructure, including sufficient electrical voltage; telecommunications infrastructure; secure spaces; and functioning, reliable equipment.
- It demands that government policymakers understand the affordances and challenges associated with educational technology and the array of inputs that must be in place, so they treat technology as a support, not as a saviour or as a silver bullet. (This latter point demands special emphasis in light of the information in Box 2).
- It requires that policymakers and decisionmakers be as savvy as the educational technology companies pushing their digital 'solutions' to educational problems, lest they waste limited financial resources that could otherwise be better invested in different interventions.
- It requires teachers who understand the conceptual underpinnings of a piece of software and know how to use, design for, and teach through and with a variety of technologies, as well as have the skills to change dominant instructional paradigms to capitalise on the benefits of technology for instruction and assessment.
- It calls for students who have the literacies, habits of mind, and behaviours to be successful participants in their own technology-based learning experiences.

Given that technology is such a highly complex intervention, the research issues around technology are also complex. Education systems are noisy. As an example, even for educational interventions in the Global South that do not involve technology, effect sizes[2] for changes in learning generally tend to be

2 An **effect size** specifies the number of standard deviation (SD) units separating the outcome scores of treatment and control groups in a study. They are expressed as the standardised mean difference (SMD), interpreted as the magnitude of the number of SD changes in the outcome for the intervention group versus the comparison group. They can therefore be used to express results from different studies on a single uniform scale of effectiveness and may be positive or negative. Effect sizes can be calculated from the means and SDs for the two groups or on the basis of information provided in statistical tests, such as t-tests and analyses of variance (Means et al., 2009, p. xiii, p. 14). An effect size is positive when the treatment group in a study outperforms the control group; it is negative when the control group outperforms the treatment group. Effect sizes of around 0.2 are typically considered to be small; 0.5, moderate, and 0.8, large in size. Effect sizes above 0.25 are

small to moderate (Evans and Yuan, 2020).[3] Despite this, and despite its ubiquity, complexity, utility, and heterogeneity, technology's many concrete, non-measurable critical functions have been distilled to one indicator—student learning outcomes as measured on test scores.

This is problematic for several reasons. Technology has manifold direct and indirect educational and personal benefits that may not lend themselves to empirical measurements, but that makes them no less valuable. The research questions asked about technology may be formulated in ways that fail to consider the complexity and contingencies associated with education and thus may not be answerable (Pedró, 2012). The diversity of technologies used in a particular setting may make it difficult to attribute specific outcomes to particular interventions, and there may be no normative expectations for improvement over time in student achievement as a result of technology use (Hill et al., 2008). However, the absence of evidence may not necessarily equal evidence of absence. Focusing on one data point—student test scores—is an insufficient measure of student learning in its fuller sense (E. Morris, personal interview, July, 2021; Spaull and Taylor, 2015). It may not give policymakers and planners the answers they need to make the decisions to drive investment and procurement. The danger is 'the baby and the bathwater' syndrome—that donors and governments may jettison funding technology in schools, not because of issues with technology *per se*, but because of decades of 'unproductive' attempts to isolate the effects of technology as an independent variable (See Box 3).

'Technology has in recent years been increasingly seen not as an isolated addition to the conventional K-12 curriculum, but as one of a number of tools that might be used to support a process of comprehensive curricular (and in some cases, systemic) reform. In such an environment, attempts to isolate the effects of technology as a distinct independent variable may be both difficult

Box 3: *Source: President's Committee of Advisors on Science and Technology, Panel on Educational Technology (1997, pp. 93-94).*

Technology is often a Rorschach test for the understanding and misunderstanding, the biases and desires of governments, private enterprise, donor agencies, and the education system itself. Although technology can support instruction, it is not a pedagogy. And while computer programmes and apps can teach students basic skills such as multiplication tables, they cannot cultivate empathy or kindness in students. No amount of technology in the world can fix curricula that emphasise rote learning. No

---

considered large enough to be educationally meaningful (Cohen, 1988; Slavin, 1990). These guidelines are only broad generalisations, however, covering many types of interventions, target populations, and outcome measures (Hill et al. 2008).

3 Across the 156 randomised controlled trials (RCTs) that measure learning outcomes, Evans and Yuan found a median impact of 0.10 SDs. Two patterns emerged, both of which are often seen in research on educational technology. First, the median impact is smaller for math assessments (0.07 SDs) than for reading assessments (0.13 SDs). Second, smaller studies (under 500 students) showed higher median impacts than large studies (above 5,000 students; 0.10 SDs vs. 0.05 SDs respectively). For the authors, this is confirmation that 'implementing effective programs at a pilot scale is easier than doing so at a national scale.'

amount of technology can compensate for teachers who are poorly prepared, poorly paid, or poorly motivated. Technology cannot improve education on its own, but education cannot be improved without technology.

1.2 OBJECTIVES AND SCOPE OF THIS THINKPIECE

This think piece outlines the research dilemmas, the benefits, and the challenges associated with educational technology with an eye towards how technology can assist the education community in meeting Sustainable Development Goal 4—inclusive and equitable quality education and lifelong learning opportunities for all. It addresses a series of topics proposed by the Global Education Monitoring (GEM) Report to assist with the preparation of the 2023 report on educational technology. To assist in this endeavour, this think piece undertakes a broad analytic review of the literature and evidence on educational technology. It identifies the main benefits, challenges, and opportunities associated with technology in education around the globe, particularly through the lenses of equity and quality, and proposes key research questions warranting further investigation by the research community in preparation for the 2023 GEM Report.

Educational technology, or information and communications technologies (ICTs) in education, is a vast domain with multiple subtopics, and education systems deploy technology in a variety of circumstances for a variety of education-related purposes. To bring some sense of order, this think piece is organised according to Inan and Lowther's 2010 framework for categorising educational technology:

- **Technologies as a learning tool:** This includes an examination of classroom uses of technology—hardware, software, computer aided instruction, personalised learning programs, the internet, computer based assessment.
- **Technologies to deliver learning:** Distance education technologies, such as online learning, mobile learning, radio, television, as well as assistive technologies
- **Technologies to support learning:** Evolving supports for technology as a learning tool and to deliver learning—open educational resources, big data, learning analytics, and artificial intelligence.

Three claims underlie this think piece. The first, stated previously, is that technology is a complex intervention, deployed for multiple constituencies, operating within complex scenarios, serving multiple purposes, and offering multiple benefits in addition to learning. Its capacity for change far outpaces our capacity to fully comprehend its benefits and challenges. Thus, it is important to reiterate that simply measuring educational technology on one outcome—for example, student learning—via one measure—such as test scores—is unproductive. This narrow focus fails to capture either the complexity of technology or of learning itself.

Second, technology is an absolute necessity in terms of learning, delivery of education, and supporting educational processes, particularly in the 21st century and particularly during a global pandemic. Even where direct links cannot be proven between technology and improved student learning outcomes, technology's benefits are manifold, particularly for the world's poorest students who need access to technology so they can begin to close the education and employment gap vis-à-vis their wealthier peers.

Third, technology is often spoken of fatalistically—as if it is natural occurring. But its equity and quality, or lack thereof, are largely the result of political, economic and educational choices. For technology to support quality and equitable education, education systems, and those who fund technology initiatives must put in place the necessary infrastructural, human capital, institutional, and educational supports so necessary for technology investments to be worthwhile.

1.3 WHAT IS EDUCATIONAL TECHNOLOGY?

For the purposes of this think piece, educational technology[4] is defined as 'any technology—including hardware, software and digital content—designed or appropriated for (any) educational purpose' (Hennessy et al., 2021. p. 8). It may be a deliberately designed piece of educational software, such as an educational video platform, or a piece of technology designed for more general use but incorporated into the teaching and learning process, such as database software. The use of this technology may be at home, at an educational institution, in an after-school programme, in a library, or at an informal learning centre, and educational technology may be used by teachers, school directors, or students.

4 Within this think piece, the terms educational technology, information and communications technologies, technology, and ed tech are used synonymously.

The above definition encapsulates the most definitive, and perplexing, innate issues associated with educational technology—its polysemy, breadth, heterogeneity, and convergence. These characteristics have profound implications for isolating and measuring the benefits of various educational technologies.

First, educational technology is not one thing—it is many things. Education technology is not *an* intervention; rather, it is an array of often overlapping, sometimes integrated, but also stand-alone tools—sometimes *either-or* and sometimes *both-and*. Table 1 attempts to categorise educational technologies as a taxonomy of interventions defined by modality: audio, video, multimedia, analogue, digital, etc. Although all of these modalities constitute *educational technology*, each has different manifestations, affordances, and challenges. Each demands distinct infrastructure, design, content, and pedagogy, and each often promotes different types of learning.

Educational technology may encompass one-to-many technologies, 1:1 technologies, peer-to-peer technologies, as well as professionally produced and/or user-generated digital content (Livingstone, 2012, p. 5). It may include technologies specific to school and that are place based (e.g. interactive whiteboards) or ones that transcend time and place but are also used within brick-and-mortar schools (e.g. online learning). It may involve technologies used for formal learning (e.g. spreadsheets or word processing software) and those used for informal learning (e.g. educational games or social media). It may require students to learn alone or with others, synchronously or asynchronously, and it may include both stand-alone and online networked technologies. Thus, outlining a taxonomy of technologies for teaching in learning, as Table 1 attempts, can often feel like an exercise in artifice because of the evolving and intersecting nature of technology.

Type of Application/Technology	Examples
Computer-based Learning	• Word processing • Spreadsheets • Databases • Electronic presentation software • Concept-mapping software • Publication software • Apps • Integrated learning packages
Visually Based Applications	• Television (analogue and digital) • Interactive whiteboards • Video

	• DVD players and DVDs
Audio-Based Technologies	• Radio broadcasts, educational programming (analogue and digital) • CD players and CDs • Podcasts • Interactive radio instruction • Interactive audio instruction
Internet-Based Technologies	• Online learning tools (learning management systems, online classrooms; web conferencing platforms; Massive Open Online Courses [MOOCs]) • Social media platforms • Virtual worlds • Immersive environments • Software-as-a service (stand-alone, web-based applications—Nearpod, Edpuzzle, etc.) • Tutoring programmes • Augmented reality • Virtual reality
Multimedia Applications	• Multimedia applications • Computer-aided instruction • Intelligent tutoring systems • Integrated learning systems • Digital learning games • Simulations
Mobile Technologies	• MP3/MP4 players • Mobile phones (feature phones, smartphones) • E-readers • Tablets • Probeware • Graphing calculators
Assistive Technologies	• Screen reading software • Voice-to-text systems/text-to-voice systems • Braille displays • Text-to-speech systems using optical character recognition (OCR) • Phones with large tactile buttons (e.g. Jitterbug) • Communication boards • Speech-output software and speech-generating devices • Symbol-making software • Alternative keyboards and input devices • Voice recognition systems

Table 1: *Categorisation of educational technologies (specifically for teaching and learning). This table is illustrative and far from exhaustive. (Modified from Burns, 2012, p. 31)*

Second, educational technology does not do *one* thing—it does many things. It delivers content, creates communities of learners, and connects tutors and experts with students. It provides access to books and information. It gathers, analyses, and reports data and builds visual, cartographic, and statistical models. It assesses learning. It is used as a productivity tool, a creativity tool, a communication tool, a collaboration tool, a design tool, and a data management tool. It is a book, a writing instrument, an encyclopaedia, a map, a file cabinet, a display device, a TV, a microphone, a (video and still) camera, a phone, a radio, and a tutor. Like another complex system—school—in which it may be used, it is composed of infrastructure and materials and involves people in an array of roles and uses. And it is dynamic—constantly evolving at a rapid pace.

Third, for all their diversity, educational technologies are increasingly integrated. The convergence of technologies (applications and devices), the rapid development of new technologies, the movement of applications onto the cloud, and the protean nature of the internet often render attempts at differentiation, categorisation, and measurement highly problematic. For example:

- Does the distinction between online learning and in-class learning make sense in a world of remote learning and where content and learning are increasingly delivered via the internet?
- Should radio and television be considered analogue technologies when they are increasingly being accessed via the Internet?
- Is television a distance technology if children are watching it in school?
- Should digital learning games be classified as internet-based, multimedia-based, or mobile forms of distance learning?
- Both computer-aided instruction (CAI) and interactive radio instruction (IRI) are often used in classrooms where there is no teacher, but why is IRI alone characterised as a 'distance' technology?
- What are we studying when we study educational technology—the device, the software, the internet, its use, or instruction? Or all of it?

Technology's accomplishments in education are considerable, from the dramatic to the mundane but necessary. Technology can help students learn content created by experts around the globe in languages the students and their teachers speak, even in the most marginalised communities. It can help young teachers learn advanced teaching and classroom management strategies, as well as help experienced teachers continue to develop their skills and share those skills with others. It gives millions of children in refugee camps access to high-quality content and skills. In all of these environments, technology can help teachers identify learning proficiencies and deficiencies in their individual students, enabling these students to receive additional instruction, social-emotional services, and learning supports on an individualised basis. At the more ordinary level, technology is critical infrastructure, enabling school administration, tracking, management, and movement of students and teachers through their educational journeys. In short, technology can make continuous learning available to anyone with a radio or TV signal or internet or mobile phone access.

But without teachers and students prepared to use, teach, and learn with and from that technology, without electricity, connectivity and equipment and the resources to maintain and operate it, technology cannot do any of this, or certainly not equitably or with a high degree of quality. As will be seen in this think piece, large gaps still persist, not just in access to technology between and within countries, but in how that technology is used and by whom. Readers will get a sense of the opportunities and challenges in the present and future. And, as readers find themselves asking more questions about the quality and efficacy of teaching with technology, they will recognise that the challenge of assuring, capturing and measuring the full benefits of technology, particularly in some of the world's weakest education systems, is indeed formidable.

1.4 TECHNOLOGY AND RESEARCH

The evidence-based research on technology within the Global South, or lower middle-income countries[5] (LMICs), particularly in donor-funded contexts, is vital for three important reasons. First, many governments have invested resources in purchasing hardware, software, and digital content in the hopes of reforming their education systems. They need rigorous, impartial research and accurate information to guide such investments to ensure that the technology they purchase provides quality learning outcomes, particularly in diverse contexts within a larger country (Burns, 2020b). Second, they need to know which technologies, alone or in combination of content formats—audio, video, text, image-based, multimedia, web-based—appear to hold the most promise in terms of reach and learning, particularly for traditionally underserved populations such as students with disabilities, religious and ethnic minorities, girls, out-of-school youth, and rural students. Third, research is needed to help education systems incorporate data and evidence into planning and decision-making on a larger scale so that governments better understand technology and disseminate evidence-based methods and models

5 Both terms will be used interchangeably in this document.

in local contexts where they can take root, spread, and scale (Wetzler and Bhatt, 2021; Christensen Institute, 2021).

However, designing and conducting quality research on educational technology in LMICs entail manifold challenges, as outlined in Table 2.

Issue/Challenge	Description
Research issues (external validity, design, methodology, data, etc.)	• Experimental or quasi-experimental quantitative studies (vs. qualitative studies) are prioritised by donors, tech companies, and international development agencies. • Non-experimental studies often show the depth of users' experiences and challenges with ICT and provide important empirical insights. However, they are often dismissed because they do not allow results to be attributable to ICT or generalisable to large populations (E. Morris, personal interview, July, 2021). • Research on educational technology is often hampered by a lack of representative samples and data. • Causal study designs may have insufficient samples, be non-experimental versus experimental, be of short duration (cross-sectional vs. longitudinal), lack sufficient control variables, be focused on proximal (vs. distal) results, or use measures that are not comparable across sites. • Monitoring data may measure usage only rather than capturing impact (Tausin and Stannard, 2018). • There are still relatively few well-established and informative monitoring systems of practices of teaching and learning (Pedró, 2012). • It can be difficult to get personal identifier IDs to link students to teachers to schools. • Approaches that are often coupled with technology, such as student-centred learning, are hard to measure using rapid methodologies and therefore harder to measure at scale (E. Morris, personal interview, July, 2021). • Outcome measures depend on accurate output measures (e.g. tracking access to technology devices and infrastructure, technology literacy, etc.)
Contextual Issues	• In many ICT education interventions, student achievement and improved teaching are incremental and not 'completely visible' by the end of the project timeline (Kennedy, 2016). • There is limited evidence from the Global South. In particular, there is a dearth of research on education in conflict and crisis settings. • Many technology companies employ research designs and use research results for product promotion (Mathewson and Butrymowicz, 2021; Hennessy et al., 2021). • Education systems often cannot measure how teaching and learning is evolving with technology because data are often not collected in pre-technology settings.

	• Research on the worth of technology as a tool for learning, for delivering learning, and for supporting learning is often not accompanied by ’expanded funding and reasonable timeframes for research to be produced ‘(Culp, Honey and Mandinach, 2005, p. 15). • Research often concentrates exclusively on the technology intervention but not on the systems and stakeholders that influence learning transfer (President’s Committee of Advisors on Science and Technology, Panel on Educational Technology, 1997).
Technology-Related Issues	• Diverse modalities and uses of ICTs—for example, the use of the internet, specific software, and a specific hardware device—are grouped under the umbrella term of ‘ICT’— which makes isolating the effectiveness of an intervention or modality difficult (Livingstone, 2012). • ICT interventions may be bundled with other non-technology interventions (e.g. curriculum reform), thus, the effects of the technology may be confounded with the effects of the non-technology intervention so that any changes might be potentially misattributed to technology (Slavin, Lake, Hanley and Thurston, 2014). • In evaluating the effectiveness of a technology initiative, national performance indicators may focus heavily on technology use, with less emphasis on instructional models or student outcomes.

Table 2: *Issues impacting quality technology-based research in the Global South*

Taken together, these issues, particularly as they relate to external validity, combined with still-evolving information about how people learn, the rapid changes in technology itself, and the reliance on the narrow measure of student test scores as a measure of efficacy, influence the quality and accuracy of claims about technology, for good or ill. They pose substantial policy and implementation challenges for governments who need generalisable data on technology effectiveness to guide scaling as well as deep, rich qualitative data to understand the how and why of effective technology use to improve student learning outcomes.

And they pose even more fundamental teaching and learning issues for teachers.

SECTION 2: TECHNOLOGY AS A LEARNING TOOL

This section examines technology as a learning tool, specifically in classrooms and primarily as used by students. To respond to the main question posed by the GEM team, this section focuses on the *benefits* of technology in terms of student learning outcomes.

In keeping with the theme of technology for learning, the section also discusses hardware, software, the internet, and assessment. It further explores the array of barriers and supports for using technology well for teaching and learning.

Before embarking on this section, several caveats are necessary for interpreting the data that follow. First, the heterogeneity of studies (e.g. experimental, quasi-experimental, and descriptive) and of contexts (i.e. countries, grades, and implementation periods) makes comparisons of technology effectiveness challenging. Second, while the meta-evaluations and single research studies cited here provide valuable information, 'no single one is capable of answering the overarching question of the overall impact of technology use on student achievement' (Tamim, Bernard, Borokhovski, Abrami and Scmid, 2011, p. 5). Third, even when and where meta-evaluations show positive benefits in the use of technology, there is often substantial variation across the studies themselves. Fourth, while different technologies are studied in isolation—for example, software interventions such as computer-aided learning or hardware interventions such as tablets—it must be remembered that hardware and software are integrated, therefore studying each in isolation may be misleading. Finally, again, it is important to remember that educational technology evolves so quickly

When computers are in labs, and are a shared resource, they are less frequently used for instruction (Weston and Bain, 2010). Making technology a ubiquitous resource—that is, available to all students—was the original impetus for one laptop per child or 1:1 computing initiatives. Thus, early adopters, such as such as the Australian state of Victoria, the US state of Maine, and nations like Uruguay and Portugal, began to provide each student with a personal device—typically a laptop or tablet—for use in school and, in some cases, at home.

Following the emergence of initially promising data from these early initiatives, the number of 1:1 computing programmes have expanded globally in educational systems that can support the cost, security, and physical and human infrastructure required of such efforts (Newhouse, 2013). These 1:1 initiatives seek to leverage students' access to technology in their classrooms so that limited or shared access to technology is no longer an obstacle to educational opportunity (Weston and Bain, 2010; Bebell, Clarkson and Burraston, 2014).

***Box 4:** The origins of 1:1, ubiquitous computing, and One Laptop Per Child programmes* that even the most recent literature may 'fail to capture successful uses of technology or fully document the dynamic digital learning tools now available' (Bebell and Burraston, 2014, p. 139).

2.1 THE DIGITAL CORE: HARDWARE, SOFTWARE, AND INTERNET CONNECTIVITY

At its very foundation, educational technology is a triad—a digital core comprising three elements. First, there is the *device*—a desktop computer, a laptop, a tablet, or a smartphone.[6] *Software*—computer programmes, apps (small applications), online encyclopaedias, or educational websites—are the digital educational content used by teachers to teach and students to learn and constitute the second element of this triad. Undergirding both the hardware and software is the *internet,* the third element. Because of the proliferation of cloud-based content and services, content and activities often reside on the internet rather than on the device itself. Therefore without *internet* access, educational software is more often than not inaccessible or non-functional, and the utility of the digital device itself severely proscribed. Although other peripheral hardware, such as interactive whiteboards, televisions, graphing calculators, may be connected to these devices, when we talk about technology as a learning tool, we refer to this digital core—hardware, software and the internet. And in this section, when we discuss technology as a learning tool, we mean *student use* of technology to complete learning tasks—solving a problem, creating a presentation, etc.

This section examines this digital core and student use of technology for learning before moving on to discuss personalised instruction and barriers and supports for teacher integration of technology. Because the most abundant literature regarding hardware focuses on 1:1 computing initiatives, we begin here. 1:1 programmes involve providing students with a device (laptop, Chromebook or tablet) as well as digital content. Some but not all provide home Internet access and/or allow students to use the device at home. It's important to note that while this section will focus on students who have access to computer hardware, such students constitute a narrow plurality in the global education system. As of 2019, 826 million students worldwide lacked access to a computer. In Sub-Saharan Africa, 89% of all students had no access (United Nations Educational, Cultural and Scientific Organization, 2020c).

6 A smartphone is a mobile phone with a touchscreen display, an advanced operating system (Android or iOS), and the ability to download apps from an online app store associated with that operating system.

2.1.1 HARDWARE

While there is no shortage of literature on 1:1 computing, the effects of digital devices (e.g. tablets, laptops[7]) on learning outcomes are decidedly mixed. Some of the more well-known national 1:1 or One Laptop per Child (OLPC) programmes in Uruguay, Peru, Paraguay, and Portugal have not shown improvements in student learning (De Melo et al., 2014; Cristia et al., 2017; Ames, 2019; Da Silva Miguel, 2014). Other studies on the effects of 1:1 computing (e.g. Hattie, 2017) estimate that 1:1 computing has a small effect size (.16), and thus potentially, a 'small positive impact' on student learning.

2.1.1.1 LAPTOPS

Autopsies of the failures of 1:1 programmes to improve student learning abound, implicating the usual culprits. In Peru, for example, most treated schools had no access to the internet and the distribution of laptops was not coupled with training teachers on how to use computers to improve teaching and learning (Cristia et al., 2017). Many other 1:1 programmes have failed to integrate computers into the existing curriculum; have overlooked the role of teachers; and have failed to provide ongoing professional development and support using technology—all emblematic of a mistaken belief in the superiority of a computer over a human teacher (Johnson, 2008; Burns, 2019a; Tausin and Stannard, 2018).

Yet, in contrast to such disappointing results, research from the United States points to statistically significant positive impacts on student learning as a result of 1:1 programmes.[8] For example, state assessments in reading from three American states[9] showed statistically significant higher outcomes for middle[10] and high school students who participated in 1:1 programmes as opposed to those who did not. Studies from initial 1:1 laptop programmes in middle school grades across several US states showed that these students outperformed their non-1:1 peers on English language arts tests (Bebell and Kay, 2010; Bebell and Burraston, 2014; Russell and Plati, 2000).

7 Chromebooks are included here as they are a specific type of laptop that run Google Chrome's operating system and Google applications. All content is stored in and accessed via the Internet (the 'cloud').
8 A result of an experiment is said to be 'statistically significant' if the differences in an initial or later measurement or measurements between two groups are likely not caused by chance for a given statistical significance level. For example, a pre-test and post-test study with a significance level of 95% means that researchers can be 95% confident that the observed results are not caused by randomness or error. It should be noted, however, that not reaching statistical significance does not necessarily mean that a result is unimportant.
9 Maine, Massachusetts, and Henrico County, Virginia. Both Maine and Henrico County, Virginia, introduced 1:1 programmes in 2003 and 2001, respectively.
10 Middle school is the equivalent of junior secondary school.

Some of the most comprehensive data on the positive impacts of 1:1 computing on student learning outcomes are drawn from the Maine Learning Technology Initiative (MLTI), a multiyear statewide 1:1 programme for all students in Grades 6–8 in the US state of Maine. Research from 2002–2011, which examined the link between laptops and writing, demonstrated that students who used laptops for writing had a greater probability of success in achieving proficiency in state writing standards and had more developed writing responses and higher scores (about 75% higher) on state tests than students who took the same state assessments with paper and pencil. This was further substantiated by another meta-analysis[11] showing an effect size of 0.32 (Silvernail and MLTI Research and Evaluation Team, 2011).

Student engagement is a broad and often undefined term in educational technology research. It is generally defined as

the degree of students' demonstrated attention, curiosity, interest, optimism, passion, involvement, and active participation in academically purposeful learning activities (Cole and Chan, 1994, p. 259; Glossary of Education Reform, 2016). Thus, engagement has cognitive, affective, and behavioural elements. Engagement is strongly linked to motivation, and research suggests a strong positive correlation between engagement and the depth of student learning (DeMelo et al., 2014; Cole and Chan, 1994).

Student engagement can be created in a number of ways—through carefully designed pedagogies; active classroom participation; collaboration in highly structured small groups with integrated accountability measures; interaction with complex and appealing stimuli, and well-designed learning activities that motivate, challenge and stimulate student interest and offer agency over their actions (Hattie, 2017; Buckley, Piacentini and von Davier, 2021). While students are often engaged, at least initially, by technology (Bebell and Kay, 2010; Tausin and Stannard, 2018; Williams and Harwin, 2016; Heflin, Shewmaker and Nguyen, 2017; Rashid and Asghar, 2016) that attachment can fade (Williams and Harwin, 2016; Heflin, Shewmaker and Nguyen, 2017).

Box 5: *What is student engagement?*

Other research findings corroborate the MLTI data. Since the early 2000s, a number of studies have consistently demonstrated that technology can improve students' writing *if* students are given open-ended prompts and *if* they go through the formal writing process—brainstorming, drafting, revising, and rewriting. The same research suggests that students participating in laptop programmes (1) write longer responses; (2) achieve higher scores on open-ended essays than students responding to the same prompt using traditional paper and pencil; and (3) spend more time

11 A meta-analysis combines the results of multiple experiments or quasi experiments to obtain a composite estimate of the size of the effect of these experiments. Even if all the constituent experiments use the same outcome and measurement scale, they generally use a 'weighted mean difference' to account for the fact that some experiments included in the analysis have larger samples than others. If the outcomes or measurement scales are not the same then they need to use a 'standardised mean difference' (SMD), which is essentially an effect size (D. Lavan, personal interview, July, 2021).

writing, editing, and analysing their writing than those without laptops (Bebell and Kay, 2010; Shapley, 2008; Russell and Abrams, 2004; Russell and Plati, 2000; Kulik, 2003).[12] In addition, a variety of research, conducted using a variety of methodologies, suggests that 1:1 initiatives involving laptops and tablets (to be discussed below) can have a number of additional positive outcomes:

- Increased student engagement and motivation (Bebell and Kay, 2010; Heinrich, 2010; Sprang, 2011; Learning Exchange, 2011 (See Box 5 for an explanation of student 'engagement')
- Decreased disciplinary problems and improved student behaviour (Silvernail and Buffington, 2009)
- Improved technology skills (Learning Exchange, 2011)
- Movement towards student-centred pedagogy and personalisation (Learning Exchange, 2011; Tamim et al., 2015)
- Greater use of the internet to search for subject-related information that is more complete and updated than information provided in lectures or by textbooks (Lei and Zhao, 2008)
- Statistically significant impacts on general cognitive skills[13] (Bebell and Kay, 2010)
- Student and teacher perceptions of improved quality of work (Sprang, 2011; Heinrich, 2010; Learning Exchange, 2011)

Finally, research from the United States shows that in terms of both engagement and achievement 1:1 programmes disproportionately benefit learners who are considered at risk: students who have struggled academically and/or behaviourally at school, students who have repeatedly failed state tests, students with learning disabilities, and students who are at risk of dropping out of school (Darling-Hammond, Zielezinski and Goldman, 2014).

A final point for consideration: the increase in 1:1 programmes may arguably be evidence that Ministries of Education and school districts have decided that access and digital equity are more important considerations than quantitative measures of student learning outcomes.

---

12 The reasons behind such gains are not clear and point to the need for more qualitative research in this area. It should be noted, too, that these studies examine writing formal essays as part of state assessments. Writing informally—note taking—for example, appears to be more highly correlated with certain types of learning outcomes than others. This is not discussed in this think piece, but more information may be found at https://link.springer.com/article/10.1007/s10648-019-09468-2.

13 As measured by Raven's Progressive Matrices test, a nonverbal test typically used to measure general human intelligence and abstract reasoning

2.1.1.2 TABLETS

Although laptops are more powerful and smartphones more portable and affordable, (smartphones are discussed in Section 3.1.2) possibly no device has increased access to education for so many as the digital tablet. As seen previously, tablets play an important role in 1:1 programmes. For these reasons, they are examined in greater detail in the next few pages.

2.1.1.2.1 NARROWING THE DIGITAL DIVIDE?

Much of the popularity of tablets can be traced to their hardware design. More robust with greater screen resolution than a phone and more user-friendly, visual, and portable than a laptop, tablets can connect to both the internet and cellular networks. These features, combined with their lower costs compared to laptops, have helped to bridge an important component of the digital divide—access to equipment (Burns, 2011, pp. 115-116). Since the inception of the first tablet in 2010, Antigua & Barbuda, Australia, Botswana, Brazil, Cabo Verde, India, Iran, Jamaica, Kazakhstan, Kenya, Pakistan, Russia, Turkey, and the United Arab Emirates have provided students with digital tablets. However, this does *not* mean that improved learning has resulted (Tamim et al., 2015; Burns et al., 2019b; Piper et al., 2017; Haßler et al., 2016). It *does* mean that thanks to tablets, more students have access to learning resources and opportunities than might otherwise be the case.

This access, along with the versatility of tablets has been particularly important for students in conflict and crisis settings, where formal learning opportunities and infrastructure (i.e. electricity and access to technology) are often unavailable. War Child Holland's *Can't Wait to Learn* programme pioneered tablet-based applied math games with interactive and multimedia activities for out-of-school children in Sudan and has expanded learning opportunities to refugee children and adolescents in Chad, Uganda, Lebanon, Jordan and Bangladesh. In Burundi, *Libraries without Borders*, in partnership with the United Nations High Commissioner for Refugees (UNHCR) and the International Rescue Committee (IRC), has used tablets, e-readers, the internet, and a generator to provide educational opportunities to 5,000 Congolese refugees in Burundi's Kavumu and Musasa camps. Organisations such as World Reader, BRCK Education, One Billion.org, and Education Development Center (EDC), all use tablets (along with other digital tools) to provide digital books and literacy and math learning activities to students across Sub-Saharan Africa (Burns et al., 2019b, p. 11). Nor are tablets exclusively for students. RTI's tablet-based

Tangerine Tutor provides video-based and scripted supports to help coaches increase the quality of their instructional support to teachers. Bridge International Academies teachers use tablets to follow scripted lessons and assess student learning.

2.1.1.2.2 LEARNERS WITH DISABILITIES AND YOUNG LEARNERS

The design of tablets—gesture based and multimodal, with touch screens and soft keyboards—and the development of a multitude of apps for tablets—have extended learning to students with disabilities and to young learners—access that might be impossible with laptops alone. Accessibility features also support student access. For example, the zoom feature allows low-vision students to magnify content so that they can follow the lessons along with their peers (Lynch et al, 2021), and speech input features help students with gross and fine motor impairment (Lynch et al, 2021; Cayton-Hodges et al., 2015).

The touchscreen, visual, app-based nature of tablets, and the ability to support videos and games make technology more accessible to young learners. In one research study examining how children across the United States learn to use informational text[14] to solve problems, low-income first graders used tablets to access the educational TV series *Molly from Denali*. In addition to watching the series, they interacted with the related apps and games installed on the tablet. This intervention resulted in statistically significant improvements in using informational text to solve problems (Education Development Center and Stanford Research Institute, 2021).

2.1.1.2.3 OTHER BENEFITS OF TABLETS

Tablets have many traits to commend them. Cayton-Hodges et al. (2015) itemise the benefits of tablets for both assessment generally and the assessment experience in particular. These include a greater variety of item presentations and responses (e.g. intuitive gesture commands, accelerometer functionality, and the potential for handwritten responses and drawings to accompany text responses). Tablet-based mathematical apps, for example, are often more interactive than typical educational assessments. Additionally, apps can collect data on response processes that are typically not present in traditional assessments (e.g. recording the order in which a diagram is drawn or redoing a problem

14 Informational text is nonfiction writing, the purpose of which is to inform the reader about a specific topic. It often uses specific features, such as headers, tables of content, and specific construction of more general language, for example, 'Tablets are smaller than a laptop and bigger than a phone.' This think piece itself is an example of informational text.

before submitting the answer). Finally, tablets provide a versatile platform for capturing explanations and reflections in speech, writing, or drawing (Cayton-Hodges et al., 2015, pp. 4, 11, 16).

Tablets have also driven changes in educational content. As educational content providers increasingly design content specifically for tablet devices, such as the iPad, the tablet has redefined the notion and format of 'textbooks.' Textbooks and digital content now include immersive environments, collaboration tools, and video and other multimedia tools, thus offering a wide range of rich and engaging interactions (Cayton-Hodges et al., 2015). Publishers of digital content substitute and supplement text with video clips or voice-overs and have reshaped web-based and mobile learning through the creation of multitudinous apps (Burns, 2011).

Cumulatively, however, these use cases and attributes have yielded inconsistent improved learning outcomes for students. Like much educational technology research, the available research on tablet-based student learning in LMICs is primarily mixed but with some moderate effects (Tamim et al., 2015). And like most research in general, results are content specific and depend on how the technology is used and what exactly is being studied (Tamim et al., 2015; Haßler et al., 2016).

In terms of evidence-based benefits of tablets, the most promising research centres on students with special needs and young children. Evidence from the US state of Maine showed that students with special needs demonstrated more engagement and active participation in learning and persistence as a result of learning through tablets (Silvernail et al., 2011). In terms of young learners, a yearlong quasi-experimental study of the impact of iPad literacy apps on kindergarteners' acquisition of early literary skills in the United States reported consistently higher gain scores for children using iPads—e.g. identifying letters that correspond to sounds—versus children in comparison settings (Bebell and Pedulla, 2015, p. 194). In other cases where learning results were shown to be significantly positive (e.g. as part of the previously mentioned *Molly of Denali* TV series), the focus of the study was on the content not the tablet, but it would have most likely been impossible for young learners to interact with learning materials were it not for the tablets themselves (Education Development Center and Stanford Research Institute, 2021).

Success or failure of tablets as learning tools depends on particular learning outcomes and, as will be discussed next, on the availability and use of certain types of software and how they are integrated into overall instruction.

2.1.2 SOFTWARE

As mentioned earlier, a device, in of itself, is of limited use without access to software applications that allows students to perform a number of learning tasks, such as writing and presenting.[15]

One of the ambiguities around the research on 1:1 computing is that the study of the *hardware* (e.g. a tablet) is often confounded with—or may even be eclipsed by—the study of the *software* (or vice versa).

Where software is the object of study, it is often a particular software package, such as computer-aided instructional programmes (referred to as *Type I* software outlined in Box 6) or adaptive learning programmes. Traditionally, ed tech research has often overlooked the most common types of software that students use, such as Microsoft Office software (part of a category of *Type II* software also outlined in Box 6) and the research that does exist often fails to connect software use to instruction. This omission represents a lost opportunity to better understand the particular conceptual design elements of certain types of software and how they might best be harnessed for learning, as well as where teachers need support with planning, designing, instruction, and assessing with particular educational software applications. Most critically, this lack of attention to software has two adverse instructional effects. First, it unwittingly casts all software as cognitively and instructionally equal, resulting often in an overuse of lower-order technology tools. Indeed, there is observational evidence of an enduring overreliance on conceptually easy or lower-order software (e.g. show and tell tools, simple games), which, although engaging and fun for students, are used at the expense of more conceptually difficult kinds of software or higher-order applications[16] that are more aligned with critical-thinking skills (e.g., graphic design programmes, modelling software, computer-aided design [CAD] programmes or database software) (Burns, 2006). Second, this lack of attention to software often results in the use of higher-level technology tools in lower-level cognitive ways.

15 In this think piece, application and software are used synonymously for programs that perform multiple tasks. An app, in contrast, describes a type of application software that performs a single function.

16 The designations of lower order and higher order here correspond to Bloom’s Taxonomy of Educational Objectives (Cognitive Domain), which classifies learning objectives into lower-order skills (e.g., the ability to identify, recall, and comprehend information) versus higher-level skills (e.g. the ability to apply information to new situations, analyse information, evaluate the worth of an idea, synthesise ideas, etc. to create a new idea or artifact) (Bloom, 1956).

Although first proposed in the 1990s, Maddux et. al.'s categorization of software as 'Type I' or 'Type II' still serves as a useful lens through which to understand the design of software applications and the demands such software places on teachers and students.

Type I applications are typically computer-based games, puzzles, and tutorials designed to help students practise skills and review concepts. Students learn 'from' the computer which generally functions as a tutor or guides the instruction. These applications are usually aimed at the acquisition of facts by rote memory and are used to diagnose and teach basic skills in a content area. The instruction is organised around specific objectives and often embodies a mastery approach to learning.

Type I applications are referred to as *full*, *closed*, or *behaviourist* applications because the software developer predetermines almost everything that happens on the screen and the type of interaction between user (i.e. student and/or teacher) and the software. The user's contribution conforms to a very limited range of acceptable responses. Everything the software is capable of doing can usually be observed in a very short period of time.

Type II applications include a variety of open-ended technology tools—for example, email, concept mapping, spreadsheets, design programmes, simulation software, open-ended games, and word processing software—that may be used to further learning in a variety of content areas. Here students learn 'with' not 'from' the computer. These applications are usually aimed at accomplishing more open-ended tasks—for example, those associated with personal productivity or creating products and projects, communicating, investigating, and discovery.

Type II applications are referred to as *empty*, *open*, or *constructivist* applications because the user (i.e. the student and/or teacher), not the software developer, is in charge of the interaction with the content. These applications stimulate relatively active intellectual involvement on the part of the user. In fact, the user has a high degree of control over the interaction between the user and machine, and there is an extensive repertoire of acceptable user input. It generally takes many hours of use before the user has seen everything that a programme is capable of doing.

Box 6: *Type I vs. Type II software and applications (Maddux et al., 2001)*

Two examples illustrate this last claim. The first involves spreadsheets which enable students to organise data numerically in rows and columns and perform a range of mathematical calculations and analyses from arithmetical to trigonometric to statistical. Spreadsheets demand both abstract and concrete reasoning skills and involve students in the mathematical logic of calculations. They enable students to model complex and rich real-world phenomena by making assumptions, coding assumptions as variables, manipulating these variables, analysing outcomes, and evaluating and displaying data both quantitatively and visually (Jonassen et al., 1998; Burns, 2006; Burns, 2012).

Spreadsheets have been shown to help students improve algebraic understanding and learn critical aspects of algebra more effectively when compared to using paper and pencil. The use of spreadsheets has been linked with students' increased ability to express general mathematical relationships using the symbolic language in the spreadsheet environment; develop algebraic understanding; assist in the early stages of children's introduction to the use of variables in formal algebraic notation; develop conceptual understanding about solving equations; and construct and analyse mathematical, graphical, and algebraic models (Jones, 2005; Rojano, 1996; Ainley, 1996; Pereira et al., 2017). Yet, in many classes across the globe, when used, spreadsheets are used as presentation tools—to display numeric information in graphs (Burns, 2006). Teachers must understand the mathematical thinking that undergirds the design of spreadsheets and how spreadsheets can create new representations of content. Without this 'technological content knowledge,' teachers will be unable to capitalise on the capacity of spreadsheets to support higher-level thinking (Harris et al., 2009; Burns, 2006).

The second example involves mind-mapping software (i.e. concept maps or graphic organisers), which allow users to create visual relationships among concepts (words, ideas, or numbers). Research points to their statistically positive impact on reading comprehension and writing skills. They allow students to organise ideas visually, create connections between those ideas, and clarify difficult-to-understand text and abstract concepts (Gouli et al., 2003; Marzano et al., 2001). This visualisation of what students know can, in turn, assist teachers in diagnosing the student's knowledge and thinking processes (National Reading Panel, 2000).

However, there are numerous types of mind maps that show distinct relationships and thus differ in their modes of analysis. Mind maps are only effective when the appropriate mind map is selected and matched with the desired type of analytic relationship. Digital mind map programmes are popular with teachers and students, but minus this understanding of the diversity of mind maps and the types of analysis each facilitates, teachers risk using a high-level thinking tool in a lower-order way. Without a focus on the types of educational applications teachers use and for what purposes, educational researchers may be incompletely assessing the relationship between technology and student learning outcomes.

Spreadsheets and concept maps constitute Type II software, which as explained in Box 6, depend on the ability of teachers to design open-ended higher-level activities that capitalise on the manifold affordances of technology. Such uses of technology pose real human capital demands on weak education systems where students and teachers may not yet have the skills to use such open-ended software in robust ways. For this and other reasons, many education systems have opted for Type I software, such as computer-aided instruction,[17] which imposes fewer demands on teachers. Computer Aided Instruction is the next topic of discussion.

2.1.2.1 COMPUTER-AIDED INSTRUCTION

In contrast to the common types of software mentioned above, one area of educational software or applications where the research has been plentiful and sustained, particularly in LMICs, is in the area of computer-aided instruction (Hattie, 2017; World Bank Group, 2020; Buchel et al., 2020).[18]

Broadly, computer-aided instruction (CAI) or computer- aided learning (CAL) is any type of instructional programme offered through a computer. Although frequently categorised as one type of technology, CAI or CAL is highly diverse and may assume a variety of forms:

- Educational games
- Simulation software
- Tutorials

The terms *personalised learning*, *individualised learning*, and *adaptive learning* are often used interchangeably but are in fact different.

With **personalised learning**, learning goals and instruction *differ* for each learner, thus, the teacher or a computer programme may customise instruction for a particular learner. This learning may be self-paced or done as part of a group (United States Department of Education, Office of Educational Technology, 2010, p. 12). Although thought of as a computer programme, personalised learning is in fact a type of instruction. (Personalised learning programmes will be examined in depth in Section 4.)

Individualised learning refers to a type of instruction that is also paced to the learning needs of different learners. However, it differs from personalised learning in that that learning goals are the *same* for all students. They can progress through the material in a self-paced manner, either on or off a computer, according to their learning needs (United States Department of Education, Office of Educational Technology, 2010, p. 12).

Adaptive learning refers to *technology* that monitors student progress in a course and uses those data to modify instruction in real time. Adaptive learning programmes do this by detecting information, diagnosing it, and enacting new tasks based on this diagnosis. Adaptive learning is not a type of instruction; it is a *technology product*. Many, though not all, personalised learning programmes are adaptive (Feldstein, 2013; Buckley, Piacentini and von Davier 2021).

Box 7: *Personalised vs. individualised vs. adaptive learning*

17 CAI has traditionally been characterised as Type I software (Maddux, Johnson and Willis, 2001) and while much of it still is, a lot of it has become less behaviourist and more constructivist, and thus more 'Type II,' in design.
18 The reader may legitimately question why CAI falls under Technology as a Learning Tool rather than under Technology to Deliver Learning (Section 3) or Technology to Support Learning (Section 4). Such a question harkens back to the Section 1 discussion on the convergent and overlapping nature of technology, and thus the need for executive decisions on the part of the author. Because CAI is used in classrooms or classroom-like settings, often with a teacher, it is classified in this think piece as a tool for learning.

- Cognitive (or intelligent) tutoring systems[19]
- Integrated learning packages
- Drill and practise software
- Diagnostic assessments or online lessons that complement non-technology activities

CAI has been around for decades, and its earlier iterations were more behaviourist, dichotomous, and focused on individualised learning. However, such programmes have become increasingly more learner-centred, personalised, and in some cases, adaptive (Box 7 explains these terms). Students learn a particular concept through a combination of animation, sound, and/or video. They may progress at their own pace and work individually, in a group, or with the assistance of the teacher. The programme generally provides feedback and increasingly 'adapts' the task to the student's ability based on student responses to a prompt. While typically used for remediation, CAI can be also used for introducing basic concepts, tutoring, enrichment, homework, supporting a new curriculum, accelerated learning, skills building, and, in some cases, as instructional supports for areas where there is no teacher or teachers are unable or unsure of how to teach particular concepts (Major and Francis, 2020).

CAI can be *integrative* (used during class along with teacher instruction) or *substitutive* (used as a substitute for teacher instruction). It can be accessed online or offline; in school, at home, or after school; with teacher support or as a self-paced instruction; and, depending on the type of CAI, as a self-directed tool.[20] Depending on the type of computer-aided programme, CAI may come with large banks of test items, and depending on the programme, CAI can be run on desktops, laptops, phones, and in some cases, gaming consoles.

CAI, like personalised learning programmes, which will be discussed next, has captured the imagination of policymakers, educational planners, and researchers in educationally challenging environments. It has a long body of research suggesting small to moderate effect sizes, thus kindling hope that it might serve as a substitute or support for schools with no teachers or poorly qualified ones and/or that it might free teachers to focus on children who need individualised tutoring (Hattie, 2017; Tausin and Stannard, 2018;

19 Although conflated with CAI, intelligent tutoring systems (ITS) are technically not the same as CAI because they are adaptive and provide stepwise tutoring. Not all CAI is adaptive; moreover, CAI provides tutoring at the answer level. ITS will be examined in greater detail in Section 4.

20 As further evidence of the polysemous nature of ed tech, the terms self-paced learning and self-directed learning are often used interchangeably. Although there is some overlap, they are different. In self-paced learning, learners proceed from one topic to the next at their own speed or pace. In self-directed learning, learners choose to initiate their own learning. They diagnose their own needs, formulate learning goals, implement learning strategies, and evaluate their own efforts and outcomes (Knowles, 1975). While this learning may be self-paced, it is not always the case.

World Bank Group, 2020). Many of the blended learning programmes that have mushroomed in countries such as South Africa, Malaysia, Brazil, and Kenya use CAI to build basic student skills in numeracy and literacy, a task for which technology is particularly well suited (Again, see Box 6 for some of the design elements underpinning CAI).

While a number of meta-evaluations show generally positive results for students using CAL or CAI, there can be wide variation within these studies. Still, the news is hopeful in terms of CAI. Kulik's 2003 meta-evaluation, focusing on 27 studies in the US, showed that students who used CAI in mathematics, natural science, or social science scored significantly higher in these subjects compared to traditional approaches—equivalent to an increase from 50th to 72nd percentile in test scores. Students who used simulation software in science also scored higher—equivalent to a jump from 50th to 66th percentile. Statistically significant gains were also reported for reading and writing.

Other research suggests a variety of small but significant effect sizes: Mo et al's., 2014 meta evaluation of game-based math CAI pointed to improved math test scores for Chinese third- and fifth-graders by .16 SDs. Snilstveit et al's., 2015 meta-evaluation of 18 studies—from East Asia and the Pacific, South Asia, Latin America, and the Caribbean (involving mainly primary grades, government schools and math and language arts classes)—revealed variations in effect sizes—from -0.01 for language arts test scores to 0.07 for mathematics test scores.

Other studies still show more *moderate* gains for CAI. In India, fourth-grade students given two hours of shared computer time per week to interact with game-based CAI that focused on the basic competencies of the official math curriculum saw improved math achievement by .35 SDs after one year and .47 SDs after two (Banerjee et al., 2007).

There is some evidence that CAI works best as a complement versus as a substitute for teaching. For instance, in a randomised controlled trial (RCT) of 198 Grade 3–6 classrooms in rural El Salvador, 3,528 students were organised into three treatment arms: (1) teacher-led classes with no CAI, (2) CAI classes monitored by a technical supervisor, and (3) CAI classes instructed by a teacher (Buchel, Jakob, Kühnhanss, Steffen and Brunetti, 2020). In terms of improved math scores, results were best for students in Treatment Arm 3: those assigned to CAI classes instructed by a teacher (.24 SD) versus those in CAI classes monitored by a supervisor (.21) (Treatment Arm 2). Students in teacher-led classes without CAI experienced the smallest gains of .15 SDs (Treatment Arm 1) (Buchel et al., 2020, p 2).

All of these studies essentially illustrate that the range of improvements vary by subject, possibly by the studies used, and by the degree of teacher involvement. What the studies do *not* show are other valuable outcomes that might be associated with such uses but that are not measured by tests: improved technology skills, more independent and self-regulated learning, persistence, and a higher degree of confidence and self-efficacy as result of overcoming a challenge or succeeding on a task. It is important to bear in mind that, while CAI has shown beneficial effects on student learning in many contexts, it has not done so in most contexts; indeed, in some cases its effects on learning outcomes have been negative (International Initiative for Impact Evaluation, 2019).

Where CAI *has* shown success, numerous conditions have been in place. These conditions include the most obvious supports: availability, quality and reliability of functioning technology (i.e. laptops or desktops); compatible hardware and software; teacher training and support, particularly in terms of using and teaching with the particular software; and the degree to which the CAI programme is integrated into an existing instructional model and aligned with the national curriculum (Snilstveit et al., 2015, pp. 235–236).

CAI programmes must be responsive to the student's learning level in order to adapt material to match the level and rate of progress made by each student so students, and their teachers, can identify patterns and learn from mistakes (Muralidharan et al., 2016; Tausin and Stannard, 2018). Programmes should embed feedback mechanisms and metacognitive strategies, such as reflection or self-monitoring. Teachers, too, should be taught how to use these computer-programme generated data to inform their own teaching. Finally, teachers must be present to assist children through their work and provide iterative, affective support that a computer cannot (Buchel et al., 2020; Tausin and Stannard, 2018).

CAI is often used synonymously with 'personalised' learning, although again, that conflation may or may not necessarily be accurate, for reasons touched upon below and elaborated upon in Section 4.1.3 Artificial Intelligence. Personalised learning is both a software application and an instructional approach, and it is the focus of the next sub-section.

2.1.3 PERSONALISED LEARNING

In contrast to many CAI programmes, personalised instruction or learning is instruction and assessment that is tailored to each student's learning needs, goals, and interests. In an environment that is fully personalised, the learning objectives content, method, and pace of instruction may all vary and are tailored to the need of the individual learner (United States Department of Education Office of Educational Technology, 2010, p. 12; Pane et al., 2017, p. 2). Having just read that, and now knowing that CAI and personalised learning are *not* necessarily synonymous, note that *CAI* and *personalised learning* will be used interchangeably in some of the research cited in this think piece.[21]

Personalised learning is far from new. For decades, integrated learning systems (ILS), which rely heavily on tutorial instruction, have offered *individualised* instruction to students with positive effects, especially in mathematics. ILS in natural and social science classes also have had an 'almost uniformly positive record of effectiveness' from the 1970s to the 1990s (Kulik, 2003:60). Such programmes have become increasingly personalised, and thus more potentially impactful, through the use of data, artificial intelligence, and advances in the understanding of how children and adolescents learn, in computer-mediated instruction, and in careful instructional design.[22]

However, personalised learning *at scale* for all students is new, and thus there are few examples from which to draw for guidance. Some US states (e.g. Rhode Island, a small state with 306 schools serving 142,014 students) and countries such as Wales, Denmark, and the Netherlands have embarked on personalised learning at scale, developing frameworks for personalised learning, expanding technical infrastructure, and using computer-based adaptive assessments (R. Culatta, personal interview, June 2021; OECD, 2020a). But these are early days.

Personalisation can be driven by computer programmes and by teachers. Thus, it may incorporate design elements as well as instructional ones. Personalisation by computers and by teachers is discussed below.

2.1.3.1 PERSONALISED LEARNING PROGRAMMES

Personalised learning programmes are *computer-based* programmes that design and deliver new types of curricula, e.g. for language learning, science, or math. This content may be proprietary content or curated from open educational resources (OER), mapped to certain competencies, and then delivered through personalised pathways.

Personalised learning programmes are highly data intensive and powered by artificial intelligence. Using algorithms or even machine learning principles, these programmes use data to create learner profiles and thus learning paths to attain a prescribed set of competencies or outcomes on these profiles (data,

21 This highlights again the complexity of educational technology noted in Section 1.3 of this think piece, viz. its convergence, intersectionality, and polysemous nature.

22 Integrated Learning Systems are sometimes conflated with 'Intelligent Tutoring Systems,' (ITS) with which they are both similar and different. ITSs are typically driven by Artificial Intelligence and will this be discussed in greater detail in Box 20 in Section 4.1.3 of this think piece.

learning analytics and artificial intelligence will be discussed in Section 4). Learning is adapted to the right level of student knowledge, with appropriate cues and scaffolds so students learn at their own pace and at their own level of proficiency.[23] It's important to note that not every personalised learning programme is adaptive, but when they are, this adaptation typically occurs in one of three ways—by allowing the student to select a difficulty level, by offering items of increasing difficulty, or by dynamically generating questions (Cayton-Hodges et al., 2015). (See Box 7 to revisit *adaptive* vs. *individualised* vs. *personalised learning*).

2.1.3.2 PERSONALISED INSTRUCTION

Education systems do not need a computer programme to personalise learning for students. In fact, teachers personalise learning all the time. One of the best ways to personalise learning for students is through small group learning and through differentiated instruction. But for that to happen, teachers need flexible furniture and skills in instructional design. They also need to be comfortable with student-centred learning approaches. These approaches involve modelling intended behaviours; scaffolding appropriate instruction and learning strategies; supporting learning through rich, social experiences; guiding and coaching students; and creating peer coaching opportunities for students so they can guide and support one another. Personalised instruction also involves designing supports such as learning stations and groupings of various sizes. Technology, aside from personalised learning programmes, can play an important role here as teachers employ technology-based supports such as choice boards, HyperDocs and playlists, as well as using technology to support alternative forms of assessment.

As will be discussed in Section 2.2, *professional development*, especially around the conceptual and logistical challenges of personalised learning, is critical. Many teachers will need help *designing* high interest, engaging, and personalised activities that provide students with choice about what to study, how to study, and how they will be assessed. They will need to learn *instructional strategies* that encourage agency and autonomy; that allow students to use the tools and resources of their choice to explore topics of interest to them; and that make use of individualised, large group, and small group work and interactions. Teachers will also require support in designing and using *assessments* that help them understand what and how their students have learned (France, 2021).

---

23 Depending on the design of the personalised learning program, and the design of the overall instructional activity in which the personalised learning program is situated, this may or may not be self-directed learning.

2.1.3.3 THE POTENTIAL OF AND CHALLENGES AROUND PERSONALISED LEARNING

Personalised learning—both via computer programmes or through personalised instruction— offers potential equity benefits. Like CAI, it may help to narrow the learning gap for the most marginalised students and for those who struggle most academically (Major and Francis, 2020). It can result in smaller groupings of students working on a task on or off a computer, which can free up the teacher's time to concentrate on students who need personalised attention, and it can support tailored, developmentally appropriate teaching 'at the right level' (Major and Francis, 2020). Personalised learning may also help to compensate for gaps in teacher knowledge or provide scaffolding for para-teachers or unqualified teachers and/or help teachers improve the quality of their teaching, particularly when they themselves struggle with particular concepts (Muralidharan et al., 2016; Buchel et al., 2020). It may meet the many diverse learning needs of a large student population with constrained educational resources, as well as offer high-dosage tutoring at low costs (Hennessy et al, 2021; Pane et al, 2017; Guryan et al., 2021).

Their promise notwithstanding, computer-based personalised programmes are far from a panacea. First, the research on personalised learning thus far is mixed, in part because these are early days, and in part because there are few models of quality personalised learning at scale. Studies from the Global North and the Global South examining low-performing students' gains in math and literacy as a result of technology-rich, personalised learning report modest learning gains (Pane et al., 2017; Bryant et al., 2020; Major et al., 2021, cited Hennessy et al., 2021). Muralidharan et al.'s, (2016) study of a personalised learning platform in India suggests that personalised learning may benefit students who are marginalised (e.g. students in rural areas or from disadvantaged families) or who struggle academically. Again, personalised learning programmes improvements have not yet been realised on a large scale (Bryant et al., 2020).

Second, computer-based personalised learning programmes do not eliminate the need for teachers. Teachers are still a necessity even with personalised computer programmes, but their roles will change from that of a transmitter of information to a facilitator of student learning. While students may benefit from computer-based learning programmes (as mentioned in the previous discussion on CAI), there is evidence that learning gains are greater in CAI classes when supporting versus attempting to replace teachers and when complementing versus substituting for conventional classroom instruction (Buchel et al., 2020; Tausin and Stannard, 2018; Banerjee et al., 2007).

Third, personalised programmes have numerous design requirements. They must be aligned to national curricula; use high-quality instructional materials in multiple representations (text, images, video, audio, animation); be engaging and attractive; reflect current research in learning sciences and instruction; be available in languages students speak; and use adaptation, with prompts, feedback, scaffolding, and dynamic content generation to respond at key points to student performance (Muralidharan et al., 2016). All of this is expensive to create and more expensive to purchase, thus begging the obvious equity question: How can poor school districts and education systems even afford to purchase such programmes?

Fourth, personalised learning programmes may collide with existing assessment systems. Ideally, as students progress along personalised learning pathways, they are assessed at the point when they are ready to demonstrate mastery over particular skills and content. Yet, many nations have fixed times in the academic calendar for assessment. Many high-stakes national assessments may not align temporally or skills wise with student learning pathways in a personalised system. Policymakers and education planners often regard their own high-stakes examinations as not simply measures of the educational efficiency of the system but as a necessary mechanism to ensure that all students are held to high standards, are offered excellent educational experiences, and that the most suitable graduates are accepted to university. These perceptions may invite scrutiny and scepticism, but they point to the larger tension Ministries of Education face in attempting to ensure equity and quality while also providing for more personalised learning (Office of Educational Technology, 2017, p.63).

Finally, personalised learning programmes may represent a slippery slope toward the 'Netflixisation' of education. These systems are powered by the predictive analytics and algorithms that will be discussed in Section 4. Thus, there is concern that, like popular streaming subscription services that push out content to users based on 'likes,' ratings, and user selections, personalised programmes will serve students a steady diet of content and topics that students may enjoy but that do little to help them improve in areas where they need the most help (Ashman et al., 2014).

There is a good deal of hope surrounding these two types of software programmes—computer-aided instruction and personalised learning programmes—hope that they will increase equity and educational quality by providing more individualised and personalised instruction and tutoring in basic concepts for learners in the Global South and hope that they can compensate for poor teaching (Banerjee et al., 2007; World Bank Group, 2020; Muralidharan et al., 2016; Pane et al, 2017; Guryan et al., 2021; Buchel et al., 2020; Kizilcec et al., 2020). While some of these applications may be stand-alone applications that are functional offline; their overall potential benefits bypass students who lack the third component of the digital core—the internet.

The internet has been a boon to universities, particularly those in the Global South, in ways too numerous to enumerate. The following examples illustrate three benefits of the internet to university lecturers and their students.

Access to research. Like university instructors everywhere, lecturers in the Global South depend on digital content for teaching and research. The internet has facilitated access to content and resources for universities in the Global South, particularly via open access research databases and subscription services (Mwantimwa, Mwabungulu and Kassim, 2021). The development of these online databases, the availability of digital content (particularly free and open-source content), and of published research means that university faculty in the Global South are consuming more research—and increasingly producing more of it, too.

Access to research points to an even larger benefit of the internet for instructors and their students—access to libraries. Many universities in the Global South have no libraries or libraries in poor physical condition with limited collections. The internet has played a vital role in the delivery of library and information services. Through digitisation of books, subscriptions to e-libraries, and the borrowing and service within a country or region, university students have greater access to more diverse and up-to-date library resources (Mwantimwa, Mwabungulu and Kassim, 2021).

Dissemination. Universities in the Global South, like their counterparts in the Global North, are increasingly using social media to recruit, inform, and build relationships with prospective, current, and past students as a marketing tool, to create brand loyalty, raise money, and gather data on prospective students so they know the types of courses, amenities, teaching, and experiences that their future customer base (students) wants. Such data can help universities improve their product (i.e. teaching, research, and the overall university experience) (Masele and Rwehikiza, 2021).

Digitising lectures. The use of screencasts, although increasingly common as part of blended learning, exploded during the COVID-19 pandemic as a major cornerstone of remote learning (Industry Research, 2021). While one can (and should) take issue with their quality and the length of screencasts—typically video-based lectures or demonstrations— they have extended learning opportunities for students. Students can watch and rewatch a lecture at their convenience, particularly before examinations, and evidence suggests that students respond better to the multichannel nature of a screencast (audio, visual, and closed-captioned text, where available) than they do to live lectures (Green, Pinder-Grover and Millunchick, 2012). Research also suggests that this verbal and visual processing can help students learn higher-level thinking skills, such as understanding concepts, and improve their performance on exams (Lloyd and Robertson, 2012).

***Box 8:** Benefits of the internet for universities*

2.1.4 INTERNET

In the early days of technology in schools, it might have been possible to envision education without the internet. Today, that is no longer true.

Although the gap is narrowing, at the height of the COVID-19 school lockdowns, 43% of the world's students lacked home internet access at a time when digitally based distance learning was vital to ensuring educational continuity in the vast majority of countries (United Nations Educational, Scientific and Cultural Organization, 2020c).

Space limitations prevent a full accounting of why the internet is critical for teaching and learning. Suffice it to say, the internet, like electricity or water, has increasingly become a utility, part of the fabric of everyday schooling and everyday life. For those schools with internet access, the internet is noticeable only when it fails to work. Without the internet, students and teachers cannot avail themselves of the plethora of digital services, software[24] and educational resources—instructional videos, live demonstrations, multimodal resources, how-to animations, discussions, experts, and classmates—and supports that are both prosaic (see Box 8) and, in many cases, striking.

The latter point is illustrated anecdotally. English speakers who spend time in junior or secondary schools in the Global South (such as the author) may have had the experience of being approached, shyly, by a student or group of students who wish to practise their English. Whether in Tbilisi, Rabat, Quito, or Jakarta, these students often speak almost flawless, unaccented, colloquial English. Having perhaps just observed the school's English classes, this English speaker might wonder how such a grasp of English is even possible given the rote and choral language instruction that seems to be norm. Thus, she will invariably ask: 'Where did you learn your English?' The answer will be almost always uniform: YouTube videos, Facebook chat rooms, WhatsApp, or multiplayer games. For many of the world's students, whether it is English, coding, athletic skills, or exam preparation, the internet, in general, and particularly social media, is their educational tool of choice.

Without access to a broadband-connected computer, secondary and tertiary-level students cannot access opportunities for real-world learning that exist beyond the classroom. As will be discussed in Section 3, online learning, when designed well, supports a diversity of learning styles and allows

24 Educational content and software have moved from being something installed on a computer to a 'service,' hence the concept of 'content as a service' and 'software as a service.' In these models, content and software are centrally licensed on a subscription basis (monthly or annual) and stored on internet-based servers. Content and software can thus be accessed via the internet on any device. In exchange for an ongoing fee, vendors take care of updates, new information, upgrades, and other processes associated with this content or software.

students to interact with a range of content that is, increasingly, multilingual and locally adapted. Online instruction, when done well, replicates the classroom environment by connecting students with their teachers and to one another in real time. The broadband-enabled virtual classroom keeps the social aspects of learning alive, including important life skills like collaboration and communication (Burns et al., 2020).

Finally, without universal internet access, the most marginalised populations—girls, students with disabilities, students in rural areas—suffer not simply from lack of access to online resources but to lack of educational and economic opportunities—disadvantages that can last a lifetime as Box 9 discusses.

2.1.4.1 OFFLINE OPTIONS TO ADDRESS THE LACK OF INTERNET

There are numerous efforts to address this educational digital divide, a few of which are discussed here. The Instant Network Schools (INS) programme, developed by UNHCR in partnership with the Vodafone Foundation, provides offline digital educational content via tablets to 126,00 refugee students and 1,600 teachers in Kenya, Egypt, Tanzania, Mozambique, the Democratic Republic of the Congo, and South Sudan. Teachers and students download these resources via the internet at community hubs and then access them offline via the local area network (Vodafone Foundation, 2021).

Other offline tools include Kolibri, an open-source platform that provides offline access to a curated library of open-licensed educational content with tools for pedagogical support. HTTrack is a free, open-source tool that allows users to download web content and store it locally. BluPoint offers digital offline technology for free to educators and allows use of digital content even when there is no internet available.

The Raspberry Pi, a small, low-cost single-board computer, runs on Linux, a free operating system, using an SD card, and it is powered by a USB phone charger (World Bank Group, 2021a, p. 4). BRCK Education uses the Raspberry Pi to enable teachers to access and cache rich and interactive websites and content (BRCK Education, 2015). Funzi.mobi is a low-bandwidth site allowing learners to study anytime (it does require some degree of internet access). The eGranary Digital Library caches educational resources via a local area network to provide educational resources to students in India, Bangladesh, and Pakistan (World Bank Group, 2021a). Offline tablet initiatives, such as, KioKit in Kenya (part of BRCK Education), e-Limu, and EDC’s Stepping Stone all offer access to pre-loaded content on tablets or phones in areas where there is no internet access. Even commercial platforms, such as Articulate Storyline, allow digital designers to make e-learning content accessible in an offline format provided it doesn't contain links to the internet.

As helpful as such initiatives and tools are, they all require the internet at some point—typically in the initial uploading and downloading of content. Thus, even many offline solutions have a hard time getting away from the need for the internet. This drives home the point that the internet is an educational necessity and its availability, or lack thereof, has profound repercussions, not just for in-school learning, but as will be discussed in Section 3, for home schooling, remote schooling, and online and blended learning. As the world has witnessed during COVID 19, the lack of internet access is tantamount to a lack of access to education itself.

Some of the widest global digital divides are within countries, and this is true whether the countries are rich or poor (Olson et al., 2011). In the US, students from poor families with no internet access have worse digital skills, poorer grades, and are less likely to seek and receive help on schoolwork or to participate in online learning (Vázquez Toness, 2020; Anderson and Perrin, 2018). These students also perform worse on standardised tests, such as the Scholastic Aptitude Test (SAT)—an entrance exam used by many universities to make admissions decisions. One-quarter of black teens report the inability to complete their homework due to a lack of digital access (versus 4% of white teens) (Anderson and Perrin, 2018). Surveys show that many English-learners lack dependable internet and technology at home, and their teachers also face a digital divide—teachers who teach English-language learners undergo fewer hours of professional development with digital learning resources than traditional classroom teachers (Mitchell, 2020).

Poor internet connectivity has long-term economic and educational repercussions. In many cases, students without internet access will possibly be disadvantaged for life. US middle school and high school students who lack internet access at home do worse in school and are less likely to attend university (Anderson and Perrin, 2018; Taglang, 2020).

In Sub-Saharan Africa, secondary school, which educates more boys than girls, is often where exposure to internet technologies begins (Burns et al., 2019b; MasterCard Foundation, 2020). But this gender imbalance extends across the poorest regions of the globe where women in LMICs are 23% less likely to use mobile internet (GSMA, 2019, p. 9). Studies in Ethiopia, Ghana, New Guinea, India, Kenya, Nigeria, Pakistan, and Zimbabwe reveal gender disadvantages when it comes to using the internet (Tausin and Stannard, 2018, p. 56). Because of caregiving and domestic responsibilities, women have less access to the internet than men, and where there is access, they report having to wait for men to finish in order to access the internet (Tausin and Stannard, 2018, p. 56). Women's access of the internet at internet cafés or community centres is further proscribed by safety concerns, particularly at night, and gender discrimination (Tausin and Stannard, 2018). The exclusion creates a negative cycle—because girls and women have less access to the internet, they know less about technology, have lower levels of digital literacy, and are less likely to use the internet for productivity purposes (see Box 12)—all of which further reinforces negative stereotypes about females and technology.

Other groups also face internet exclusion. Across the globe, students in rural areas have 40% less access to mobile internet than urban students (GSMA, 2019, p. 8). The internet is particularly valuable for people with disabilities who often use the internet to find social groups and communities and form and maintain relationships without the stigma they'd face in in-person settings. Yet social media platforms often fare poorly in terms of accessibility features, such as keyboard shortcuts, colour contrasts, and alt text for images (Dobransky and Hargittai, 2021).

This educational opportunity is driven by a wealth gap that markets alone cannot address (Global System for Mobile Communications, 2016). Government, industry, and international donors will need to collectively invest in fibre-optic infrastructure for reliable, low-latency, high-speed broadband. Studies show that the true economic value of a fibre infrastructure far exceeds the cost of installing and maintaining the infrastructure and inclusive broadband internet access can save education systems money in the long run. For instance, savings to New Zealand's education system is estimated to be $3.6 billion NZD over 20 years—due to lower costs resulting from skill enhancement, reduced cost of course materials and savings on educational field trips and providing additional home schooling and distance learning to traditionally excluded populations (Alcatel-Lucent, 2012).

Box 9: *Who is impacted by digital exclusion?*

2.1.5 TECHNOLOGY-BASED ASSESSMENTS

Assessment is an integral part of student learning, thus no discussion of technology as a learning tool is complete without it.

One of the most valuable educational benefits offered by technology is *automation*—the ability to reduce manual labour so that certain tasks are performed more efficiently, at a higher volume, and at scale. Many national assessment systems have wrestled with gathering enough data to draw reliable conclusions without creating undue burdens on teachers, undue expense for an education system, and unduly delayed results for learners (Burns, 2011).

Technology has done much to automate assessment—in exam construction, test item generation, automatic grading, recording, and reporting data at scale. Computer-based assessments, such as those constructed in a learning management system (LMS), can support dynamic and individualised assessments and allow for multiple test administrations. They measure student learning in multiple formats—quizzes, discussions, projects, performance-based assessment, e-portfolios, and so forth—thus, assessing knowledge and facts as well as higher-level skills, such as students' ability to analyse, synthesise, and evaluate ideas, arguments, and information.

Computer-based testing can vertically and horizontally align tests and, if universally designed (Box 15 defines Universal Design for Learning), potentially makes assessments more accessible to learners with disabilities than is the case with paper and pencil tests. For example, screen readers, magnification tools, and text-to-voice or voice-to-text applications (discussed in Section 3.1.5) can help learners with visual, auditory, and motor impairments. They can also help learners with learning disabilities, such as dyslexia, and those who simply need more time to complete a test (Burns, 2011, p. 163).

Thus, as a result of technology, the automation of assessments can (1) lower the cost differential of testing because it takes less time to score and store; (2) enable a quick turnaround of assessment data to the teacher and students, allowing teachers to assess student performance at a much more granular, detailed level; and (3) provide more reliable scoring and valid data interpretation (Burns et al., 2008: 18, cited in Burns, 2011, p. 162).

2.1.5.1 COMPUTER ADAPTIVE TESTS

A powerful variation of technology-based assessments is computer adaptive tests (CATs), which are a type of computer-based test. These can be used in class, as part of CAI/ITS programmes, personalised learning programmes or in online learning programmes, to specifically measure targeted learning outcomes. Their main goal is not to assign a grade but rather to estimate the point a student has reached in terms of learning progression, and they can collect sufficient data for highly reliable results in a relatively short time (Masters, 2021). CATs do this by using the power of technology to select items presented as the test progresses, based on students' answers. CATs typically use item response theory, which measures the difficulty of each test item as well as the probability that the learner will get it right. The computer then matches the difficulty of the question to the student's previous performance so that scores are always comparable to the previous administration. This means that no two students, even if seated next to one another and being assessed on the same content, would take the exact same test, although they would be assessed on the same constructs (Burns, 2011, p. 162). CATs offer a glimpse into the future of technology-based assessment; however, few countries—Wales in an exception—have adopted CATs at scale (Organisation of Economic Cooperation and Development, 2020; Masters, 2021).

2.1.5.2 ASSESSMENT FOR LEARNING

Yet, while technology has dramatically changed assessment, its greatest impacts have been on summative assessments. These include large, national, and international high-stakes examinations assessments (e.g. the Abitur, Baccalaureate, O and A-Levels, Early Grade Reading Assessment [EGRA] or Annual Status of Education Reports [ASER])—that is, typically high-stakes exams at the end of grade levels or learning cycles where assessments are used for choosing, sorting, and screening for accountability measures or to certify learning. This impact is particularly notable in the development, administration, scoring, and reporting of such summative assessments.

However, there has been far less innovation in the areas of technology-based formative assessment to improve instruction and student learning. Assessment theory notes that students learn best when assessment is part of, not separate from, instruction and that high-quality, formative classroom assessment activities can improve student learning outcomes. Rather than separating assessment from instruction and making assessment a purely summative exercise, assessment should be intertwined with actual instruction. Interactive technologies offer opportunities for more engaging pedagogy supported by new ways of formative assessment that is holistic and engaging (Timmis et al., 2015).

There are multiple ways teachers can use technology for formative assessment. For example, they can use polling software to diagnose students' prior knowledge or understanding of a curricular topic. Audio and video extensions to software can allow teachers to provide rich, dynamic individual or group feedback, which can support motivation and engagement in the learning process. Mini quizzes can support retrieval practice, thus helping to consolidate new learning. Given choice, students can represent their progress and achievements via portfolios, projects, or other types of alternative assessments. Technology can be used for peer assessment and real-world activities—to build models, assess a problem, create scenarios, analyse a budget—that can assess creativity, deeper understanding and problem solving (Timmis et al., 2015; Inan and Lowther, 2010).

2.1.5.3 GAME-BASED ASSESSMENTS

One area that has generated excitement is game-based assessments. These assessments include rich, scenario-based programmes, such as virtual worlds, simulations, and multi-user virtual environments. They provide a developmental sequence of challenges that gradually increase in difficulty so that players are working at their highest abilities. They are also adaptive (e.g. ALGAE [Adaptive Learning Game Design]) and incorporate elements such as scores and leader boards. Students can develop conceptual thinking by interacting with and manipulating complex systems, which allows designers to measure difficult-to-assess skills, such as higher-level thinking skills and 21st-century skills of persistence, creativity, self-regulation, problem solving, and collaboration as well as affective states (such as engagement) via the use of eye-tracking and facial recognition software. Game-based assessments also provide feedback, hints, and just-in-time resources, as well as capture and store multiple sources of data over long periods to provide information about the student's work so they can tailor tasks and problems to the student (Buckley et al., 2021; Gee and Shaffer, 2010).

Despite these potentially exciting technological developments, like everything in education, questions about equity and quality persist. The benefits of technology-based assessments, particularly CATs and technology-based alternative assessments, remain confined to wealthy education systems or schools. Low-resource educational systems and schools often lack the funding to buy the technology necessary to support these assessments, thus deepening the digital divide.

Further, technology alone cannot make good assessment happen—it is simply the delivery and automation system for assessment. Good assessment depends on highly skilled content experts, psychometricians, designers, and assessment experts to create assessments that are valid, reliable, fair, and transparent and that measure not simply declarative and procedural knowledge, but conceptual, higher-level thinking skills, aptitudes, and a full range of cognitive and affective skills. The technology is the easy part. Designing good assessments remains the challenge.

2.2 TEACHERS: BARRIERS AND SUPPORTS FOR EFFECTIVE TECHNOLOGY USE[25]

What is left unsaid in many studies showing successful uses of educational technology is the effect of quality instruction and thus the role of the teacher. Indeed, it is not possible to talk about technology for learning without talking about teachers and teaching. If education is an ecosystem, then teachers are the keystone species within this ecosystem.

The remainder of Section 2 examines the challenges teachers face and the supports they need to successfully integrate technology into teaching and learning. Much of what follows in this section applies to teachers teaching via technology (Section 3). Since Section 2 involves technology as a learning tool, particularly within classrooms, the challenges of integration are best discussed here.

Successful technology *integration*—that is, routine but thoughtful technology use targeted at improving teaching and learning—is tightly linked to the practices of the teacher (Hew and Brush, 2007; Inan and Lowther, 2010; Ertmer, 1999; Ertmer and Ottenbreit-Leftwich, 2010; Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur and Sendurur, 2012). Attaining technology integration involves a 'multidimensional relationship' between the teacher, technology use, and a constellation of often discrete yet integrated personal, environmental, cultural, and behavioural conditions or factors that occur within a particular professional and organisational context (Veenstra, 1999, cited in Tondeur et al., 2008 p. 495; Williams and Harwin, 2016; Burns, 2019a). Ertmer (1999) first categorised these conditions as 'first order' and 'second order' barriers to technology integration. First-order barriers concern basic infrastructure. Second-order barriers touch on the teachers, and third-order barriers—proposed for purposes of this

25 Much of this section (Section 2.2 to 2.3.3.3) has been modified and adapted from pages 41-46, Burns, M. (2019). For want of a good theory: Considerations for technology integration in well-resourced schools. M.A. Clausen (Ed.) A Closer Look at Educational Technology, pp. 29-90. New York, NY: Nova Science Press. Used and adapted with permission from Nova Science Press.

think piece—focus on external organisational factors in the teachers' professional environments that are beyond their control.

While these barriers are elaborated upon in this section on technology as a learning tool, they largely apply to the remaining sections of this report—technology to deliver learning and technology to support learning.

2.2.1 FIRST-ORDER BARRIERS

First-order barriers are extrinsic to teachers and are typically resource-based. They include electricity supply, the degree to which a school or Ministry of Education provides access to sufficient amounts of functioning technology and to digital and analogue teaching and learning resources to support successful technology use, the quality of telecommunications infrastructure, and the availability of time and technology training for teachers and students (Cennamo et al., 2010).

The larger narrative on educational technology in the Global South often suggests that failures around educational technology are an inevitable result of the contexts of poverty and privation, which make access to such supports impossible. It is incontrovertible that teachers and students need these basic supports. It is also certainly true that it is far easier to successfully implement and integrate technology in wealthy environments with better educated teachers, than in economically disadvantaged ones with poorly educated ones. However, there is also some, albeit limited, research suggesting that poor uses of technology—lower-level uses of higher-level tools and traditional, teacher-led instruction—also abound in wealthy contexts where first-order supports are abundant (Burns, 2019a).

2.2.2 SECOND-ORDER BARRIERS

Even if every first-order support were in place, teachers would not automatically begin to use technology to achieve the kinds of student learning outcomes desired by policymakers. Effective technology implementation is often impeded by *second-order barriers*, which are more intrinsic to the teacher, less tangible in nature, and therefore harder to overcome than first-order ones (Ertmer, 1999, pp. 51, 52). These are discussed below.

2. 2. 2. 1 PERSONAL CHARACTERISTICS

The first set of intrinsic factors have to do with teachers' personal characteristics. These include teacher *readiness* to integrate technology, which comprises teachers' experience and proficiency with technology combined with a willingness and a feeling of preparation to teach with technology and an openness to change (Inan and Lowther, 2010; Ritzhaupt et al., 2012; Tondeur et al., 2008; Rogers, 1995).[26]

Teacher beliefs about technology, such as whether or not it can help them achieve their most important instructional goals, and their beliefs about pedagogy—particularly their views of teacher-centred versus learner-centred pedagogies—also correlate with technology use since they provide students with the scope, support, and space to use technology in more authentic ways (De Melo et al., 2014; OECD, 2015; Inan and Lowther, 2010; Tondeur et al., 2008; Abu Bakar et al., 2009; Ertmer et al., 2012). Finally, in terms of personal characteristics, *teacher confidence* and *teacher self-efficacy* may be more important than skills and knowledge among teachers who implement technology in their classrooms (Ertmer and Ollenbreit-Leftwich, 2010; Dimock et al., 2001; Wozney et al., 2006; Burns, 2019a).

2.2.2.2 PEDAGOGICAL FACTORS

A second set of factors necessary for successful technology integration focuses on pedagogy, specifically challenges around adoption of new instructional practices. Teachers in many systems are being tasked with simultaneously adopting two complex interventions—technology and student-centred learning. This has resulted in numerous challenges, as will be discussed.

Much has been written about the importance of preparing learners for a knowledge-based economy grounded in innovation, creativity, and problem solving. At a policy level, secondary and tertiary education institutions are tasked with producing students with strong maths, science, and technology skills who can think independently; work collaboratively; exhibit skills of inquiry, analysis, oral and

26 An obvious question in terms of teacher personal characteristics involves gender, age, and years of teaching. Analyses of female and male teachers' experience, dispositions toward, and use of ICT is that any differences are small and/or inconsistent across countries (Gebhardt, Thomson, Ainley and Hillman, 2019). Inan and Lowther (2010) suggest that teachers' demographic characteristics (years of teaching and age) negatively affect their computer proficiency—and that computer proficiency positively affects teachers' ability to integrate technology (p. 146). However, other research (Tondeur et. al., 2008) disputes this.

written communication, and social negotiation; and who can transfer their knowledge and skills automatically to novel situations (World Education Forum, 2016; MasterCard Foundation, 2020).

This demand for future workers to fuel the knowledge economy, in addition to research from the Programme for International Student Assessment (PISA) and the Teaching and Learning International Survey (TALIS), cumulatively argues for using technology in combination with student-centred instructional approaches (Organisation for Economic Cooperation and Development (OECD), 2018; OECD, 2015). Box 10 explores the research on teacher-centred and student-centred pedagogies.

One of the most enduring tensions in education is that of teacher-centred versus student-centred instruction. Teacher-centred instruction is characterised by the teacher's control of the pacing and adaptation of instruction (Stockard, Wood, Coughlin and Khoury, 2018). Its dominant manifestation is whole group teaching and *direct instruction*—the teacher transmits knowledge about concepts, skills, and procedures via demonstrations, lectures, screencasts, or online presentation to students as one large group.

Student-centred learning (often called *active learning*) allows students to control the pace of their learning and adopts a more social approach to learning. It attempts to make learning more adaptive and individualised. Student-centred learning is not one method, but rather a family of approaches, including cooperative learning, collaborative learning, project-based learning, problem-based learning, discovery learning, and inquiry-based learning (Burns, 2011, pp. 152-154). Examples of these methods might involve solving a real-world problem, jigsaw approaches, reciprocal teaching, discussions and debates, peer tutoring, learner co-creation of a product collaborate via Google Docs, or working in pairs to complete a choice board. Teacher-centred instruction has often been portrayed as ineffective, yet the research does not support such an assertion. A 2018 meta-evaluation of 413 study designs and almost 4,000 effect sizes assessing direct instruction (the most common form of traditional teaching) reported medium effect sizes for reading (0.51), math (0.55) and language (0.54). This suggests that teaching basic skills and competencies through direct instruction is at least as effective as the best forms of individualised and adaptive instructional systems and approaches (Stockard, Wood, Coughlin and Khoury, 2018).

Yet strong evidence also exists that student-centred instruction leads to improvements in learning with primary and secondary school students. A 2019 meta-evaluation of 299 studies of 43,175 students in the United States, Europe, and Australia from 2000 to 2017 assessed the overall impact on student achievement based on student-centred instructional methods. This study found an average effect size of medium strength (0.44) as well as a demonstrated (subtle but significant) linear relationship between more student-centred classroom instruction and effect size ($p = .03$) (Bernard, Borokhovski, Schmid, Waddington and Pickup, 2019, p. 4). These overall results support two conclusions (1) the efficacy of engaging students in student-centred learning as part of a comprehensive educational approach and (2) the adoption of different instructional styles as the teaching context (e.g. different phases of instruction—presentation of the subject matter, individual application, etc.) requires (Bernard, Borokhovski, Schmid, Waddington and Pickup, 2019; Burns, 2011).

Box 10: *Teacher-centred vs. student (learner)-centred Instruction*

However, combining the use of technology and student-centred pedagogies to improve student learning outcomes is challenging for most teachers, particularly for many teachers in the Global South where preparation in and support for such methodologies may be limited. Research documents many of the challenges that teachers face when implementing student-centred pedagogies (with and without technology), including the following:

- Concerns about time to cover the curriculum (Kazempour, 2009; Tamim and Grant, 2013)
- Understanding the relationships between the affordances of a range of ICT resources and particular subject domains (Webb and Cox, 2004; Watson, 2006; Moeller and Reitzes, 2011)
- Anxieties over students' performance on external exams (Kazempour, 2009; Tamim and Grant, 2013; Selwyn, 1999)
- Resistance to change in the shift from traditional methods (Qhobela, 2012)
- Fear of failure or embarrassment in front of students (Dimock, Burns, Heath and Burniske, 2001; Burns and Dimock, 2007; Burns, 2020a)
- Peer pressure from other teachers (Jackson and Bruegmann, 2009; Lewis, 2014; Dimock, Burns, Heath and Burniske, 2001)
- Problems with classroom space and flexibility of furniture (Tamim and Grant, 2013)
- Lack of awareness and comfort with different pedagogical practices (Ertmer and Ottenbreit-Leftwich, 2010)
- Apprehensions about classroom management (Tamim and Grant, 2013; (Dimock, Burns, Heath, and Burniske, 2001)
- Difficulty selecting and designing with the most appropriate technologies to support specific curricular goals (Harris et al., 2009)

With and without technology, student-centred learning involves the deployment of *cognitive activation strategies*, such as questioning, predicting, problem solving, applying, summarising, analysing, synthesising, and evaluating information, or higher-level thinking (OECD, 2018a, p. 57; Bloom, 1956). This focus of higher-level thinking is particularly challenging for many teachers across the globe, even those who enthusiastically embrace technology. The reasons often have to do with teachers' incomplete preparation in the subject matter they teach as well as national curricula and high-stakes assessment systems that promote and measure students' knowledge of facts and declarative knowledge. National assessment systems will be discussed in Section 2.3.3.4.4*, Systemic Barriers*.

Layered over higher-level thinking with technology are numerous other demands regarding teaching. For example, teachers are increasingly tasked with helping students learn a complex array of both digital and life-related skills and dispositions. These extend beyond mastery of content knowledge to skills such as information literacy, civic engagement, and work readiness, as well as dispositions as encapsulated under the rubrics of social and emotional learning (SEL) or college and career readiness, like the ability to collaborate, be a lifelong learner, and demonstrate tolerance.

Teachers at every level of the education system, including institutions of higher education, may be uncomfortable with these demands, especially those that focus on higher-level skills and SEL. The author's interviews with teachers, particularly at the upper secondary and tertiary levels of the education system, reveal that teachers often feel they are sacrificing content to the cultivation of skills that may not be their responsibility. They may be concerned about, or feel ill-equipped to, design activities that are complex—i.e. that are both difficult and composed of multiple sub-activities. Particular methodologies that fall under the rubric of student-centred learning, such as project-based or problem-based learning, often introduce elements of confusion and frustration to students, which teachers may regard as emotions to be avoided. In a problem- or project-based learning approach, not every problem will have a solution, which can be discomfiting to teachers and students alike. Finally, student-centred learning, with and without technology, may lead students to topics for which the teacher has no expertise, such as questioning the veracity of a scientific claim in an online article or solving a water quality issue (Burns, 2020a).

2.2.3 THIRD-ORDER BARRIERS/SUPPORTS

As a result of the COVID-19 pandemic and remote teaching, many teachers have reported improved technology skills—although the degree to which this is true across the globe is not yet fully known (Klein, 2021). Prior to the pandemic, however, many teachers struggled using technology and mastering new digital pedagogies—especially those that engaged learners in collaborative and innovative ways (Dooley, Ellison, Welch, Allen and Bauer, 2016; Ertmer and Ottenbreit-Leftwich, 2010; A.M. Raad, personal interview, May, 2021; Perifanou, Economides and Tzafilkou, 2021). For instance, more than 60% of teachers in the European Union reported being 'not well prepared' to use digital technologies for teaching, particularly for more complex digital tasks such as coding, programming, or robotics (OECD, 2018b). The OECD's *Teaching and Learning International Survey (TALIS)* noted that fewer than half of the world's teachers felt well prepared to use technology in their classrooms (63% of Shanghai and 60% of Singapore teachers feel most prepared—the highest across the globe) (OECD, 2018b; OECD, 2020b). And the *International Computer and Information Literacy* 2018 survey showed that although 95% of teachers reported 'high confidence' in their ability to find useful educational resources on the internet, and 84% could create presentations with simple animations, confidence dropped when it came to using technology to assess students (78%), contributing to an online discussion (58%), and collaborating with others over platforms (57%) (Perifanou, Economides and Tzafilkou, 2021). Almost half of U.S. teachers reported needing more training than they currently received in using technology effectively (Office of Educational Technology, 2017).

Not surprisingly, teacher skills in and confidence with technology reflects the larger structural digital divide. Rural teachers in France reported less confidence with and use of technology than urban teachers (Institut national de la statistique et des études économiques, 2019). Teachers in wealthy schools reported stronger technology skills, more technology-related professional development, and more frequent use of technology for teaching than teachers in poorer schools. In OECD countries, 65% of teachers reported having the necessary technical and pedagogical skills and training needed to use digital devices in teaching, and 53% allowed their students to frequently or always use digital technologies for projects or assignments (OECD, 2018b). Italy seems to have been an exception. Only 20% of teachers reported having had any kind of technology training as of 2019 (Editrice Morcelliana, 2020). But in Latin America, even in large urban areas with relatively robust internet access, more often than not, teachers reported being unfamiliar with the use of the internet in the classroom and with digital practices in general (A.M. Raad, personal interview, May, 2021; Martínez, Adib, Senne and Pérez, 2020).

As the globe tentatively emerges from the COVID-19 pandemic, we should know more about changes in teacher confidence with and proficiency in technology. Teacher capacity to teach using educational technologies in general, and to teach online in particular, will most likely vary across countries. But if effective teaching requires effective technology use, pre-COVID-19 data suggests there is still much work to be done almost everywhere in terms of quality in-service professional development that will help teachers use technology, develop technology-integrated lessons, and teach effectively through and with technology.

Box 11*: Teachers' technology skills prior to COVID-19 school lockdowns*

Beyond access to resources (a first-order barrier) and conditions involving teachers themselves (a second-order barrier), teachers often face situations and barriers beyond their control which also impact their ability to successfully integrate technology. For purposes of this think piece, these are categorised as 'third-order barriers.' They represent conditions in the teacher's professional environment that are beyond his/her control and are, in fact, most often controlled by higher levels of government or the education system.[27]

2.2.3.1 FACTORS RELATING TO PROFESSIONAL DEVELOPMENT

A logical extension of any discussion of teacher integration of technology must ultimately address issues of teacher professional development and support, especially regarding teaching with and through technology.

Teacher professional development as discussed here includes access to ongoing, quality instruction (training) as well as immediate and responsive pedagogical supports. A key element here is the availability, frequency, continuity, and quality of professional development (Ertmer and Ottenbreit-Leftwich, 2010).

Technology is a complex intervention but both in wealthy, and primarily poor contexts, teachers are often ill prepared to fully master technology in all of its complexity. As the following paragraphs discuss, technology professional development is a multi-layered, time- consuming, and involved process that is neither fast, easy, nor inexpensive (Burns, 2011; Hord, Rutherford, Huling-Austin and Hall, 2006).

2.2.3.1.1 PROFESSIONAL DEVELOPMENT FOR TECHNOLOGY INTEGRATION

Professional development to help teachers successfully integrate technology should embody research-informed characteristics, six of which are noted here. First, and most fundamentally, professional development must help pre-service and in-service teachers understand the various technology tools at their disposal—hardware, software, and the internet—and how to use these tools (Angeli and

27 There is some research—Tsai and Chai, 2014—that discuss 'third-order barriers,' but these centre on teachers themselves versus on factors external to teachers, for example, the availability of professional development, which are discussed instead in this think piece.

Valanides, 2009; Inan and Lowther, 2010). Rapid changes in existing technologies and development of new technologies speak to the need for continuous technology training.

Second, this professional development must not end with simple use of the technology tool, as is so often the case. It should help teachers deepen their understanding of how technology connects to and can create new representations for specific content as well as the conceptual design of various software tools teachers will use to teach (Harris, Mishra and Koehler, 2009; Burns, 2006). As noted earlier in Section 2.1.2, a teacher cannot use spreadsheets to deepen understanding of statistics if the teacher lacks a strong grasp of statistics or does not understand the degree to which spreadsheet programs adequately represent simple and complex statistical functions. Teachers cannot capitalise on the benefits of computers for writing if they know how to use a word processor but do not know how to teach the writing process.

Third, professional development should model for teachers how various technologies can be used in teaching and what good teaching with technology actually looks like in practice. This can involve two approaches:

- Observing the successful student-centred, technology-integrated practices of other teachers helps teachers increase their understandings of what new procedures look like (Zhao and Cziko, 2001; B. Avalos, personal interview, June 2021).
- Designing professional development that places teachers in the role of learners. By experiencing learning from the point of view of a student, teachers begin to empathise with their students as learners and reflect on their own pedagogical practices and how they promote or impede learning (Burns and Dimock, 2007).

Fourth, it should help teachers identify which technologies support specific curricular goals and how technology can be combined with pedagogy to help students learn the most difficult concepts associated with a domain (Ertmer and Ottenbreit-Leftwich, 2010; Angeli and Valanides, 2009; Ertmer, 2005; Hew and Brush, 2007; Burns, 2019a; Elmore, Peterson and McCarthy, 1996, cited in Ertmer, 2005).

In the secondary and tertiary levels of the education system, particularly, this involves, not simply imparting knowledge, but helping teachers and university instructors develop their own higher-level thinking and SEL skills so they can help students solve problems and implement creative ideas and solutions in varied and changing situations (World Economic Forum, 2016).

Fifth, professional development must provide teachers with time to become instructional designers with technology. This involves learning how to plan, design, practise, and receive feedback on student-learning activities that focus on integrating content, technology, and pedagogy to deepen student learning[28] (Harris et al., 2009; Tsai and Chai, 2012).

All of these opportunities must be coupled with ongoing classroom-based supports, such as coaching or mentoring (face-to-face, blended, or virtual) and professional learning communities so teachers can attempt to integrate these new approaches into their classrooms through more frequent support and tighter feedback loops (Hord et al., 2006; Burns and Dimock, 2007; Burns, 2011).

Finally, professional development initiatives, and those who fund and design them, must begin with an awareness that transforming a traditional classroom using technology is neither fast nor easy. Any change, particularly one as complex as instructional change, is non-linear, often recursive, and takes years to internalise and institutionalise (Hord et al., 2006; Rogers, 1995; Burns, 2011).

Research on teacher change distinguishes between teachers' espoused or articulated beliefs—what they say they believe or value—and their deep or embedded beliefs—the drivers of classroom practice. Teachers who receive little or no school-based training and support experience minimal change in these embedded beliefs and values. In contrast, ongoing and high-quality school-based professional development and support disrupts this cycle, providing both pressure and support for teachers to change what they do. When teachers see positive changes as a result of their actions, their deeply held beliefs about traditional instruction or technology use may conflict with what they in fact witness in their classrooms (Hord et al., 2006; Ertmer and Ottenbreit-Leftwich, 2010). Teacher mindsets can then begin to change as they begin to see that 'teaching is not effective without the appropriate use of ICT to facilitate student learning' (Ertmer and Ottenbreit-Leftwich, 2010, p. 255).

28 One such framework is Technological Pedagogical Content Knowledge (TPACK). This instructional design framework identifies the main components of technology, pedagogy, and content and guides teachers in connecting content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK) and their sub-components to produce effective discipline-based teaching with educational technologies (Harris et al., 2009).

2.3.3.2 ORGANISATION AND CULTURE

The larger educational culture—how schools are organised, leadership social dynamics and relationships at the school, and the larger educational culture—have an obvious impact on technology integration.

The most critical organisational factors supporting technology integration appear to centre around three elements: principal leadership, organisational context, and teacher collaboration. These are discussed in the following pages.

2.3.3.1.1 PRINCIPAL LEADERSHIP

The principal's role in promoting teachers' technology use and integration is key. Studies of technology adoption and integration in universities in New Zealand, Australia, and the United Kingdom suggest that without strong educational leaders who provide both pressure and support to teachers in the use of technology for effective instruction, educational technologies do not accelerate improved teaching and learning (Marshall, 2010). Pressure includes explicit expectations, coupled with accountability, that technology will be used. Support involves logistical, material, instructional, and supervisory support (Hord, Rutherford, Huling-Austin and Hall, 2006; Dimock, Burns, Heath and Burniske, 2001). Without this pressure and support from school leaders, the use of educational technology simply reinforces the *status quo* of existing beliefs and practices and is unlikely to improve student learning outcomes (Marshall, 2010).

The principal significantly influences the conditions for technology adoption and integration. Principals do this by communicating a shared vision and agreed-upon goals for technology as well as expectations for new instructional methods facilitated by technology. They encourage practices that strengthen a culture of collaboration and promote an ethos that empowers teachers to take risks and experiment (Ertmer et al., 2001; Moeller and Reitzes, 2011). Above all, they apply appropriate amounts of pressure and support. While principals do not need to know how to use every technology a teacher is expected to use, they should understand its general uses and affordances otherwise they cannot effectively advocate for its use.

The important role played by principals in teachers' adoption of innovations has been corroborated in a number of studies (Leithwood, Seashore, Anderson and Wahlstrom, 2004). In one study—a crosscountry examination of how teachers adopt technology in pedagogically meaningful ways in schools in the Maldives and Tanzania—the author concluded that school-wide innovation with technology occurred only where 'the principal's vision and motivation were of central importance' (Somekh, 2008, p. 457) and the innovation led to a 'change in the nature of teacher–teacher relationships, based on collaboration and mutual support' (pp. 457–458). In short, a good principal or supervisor can help teachers use technology well to support curriculum and instruction; a poor one cannot.

2.3.3.2.2 ORGANISATIONAL CONTEXT

The organisational culture of the school may facilitate or impede teachers in using technology to attain curricular and instructional goals. Organisational culture involves factors such as the degree to which there is a shared vision, leadership, and supervisory and peer pressure to use technology; and a change-oriented environment that supports innovation and motivation and encourages innovation and experimentation with technology (Ertmer et al., 2001; Leithwood et al., 2004; Hord et al., 2006).

Schools themselves are complex structures situated within an even larger organisational context, like a region or district, that is often proscribed and risk averse (Somekh, 2008). National, regional and local regulatory frameworks and policies and attitudes of the local community and parents can either constrain or enable innovation and the degree of experimentation or risk-taking that teachers take using technology, especially to support more student-centred approaches (Somekh, 2008). Many researchers argue that technology integration is possible only when systemic changes are made in the way teaching and learning are ultimately viewed, organised, and occur within educational systems (Sangra and Gonzalez-Sanmamed, 2010; Somekh, 2008; Hew and Brush, 2007).

2.3.3.3.3 TEACHER COLLABORATION

The existence and quality of teacher collaboration is also critical. A high degree of social capital and social trust has been identified as essential to changing both teachers' epistemological beliefs and their teaching practices with technology (Li and Choi, 2014). For technology to be used to extend and deepen student learning, teachers need a network of collaborative and mutually supportive relationships.

When we talk about students' technology skills, we are often discussing four sets of distinct skills:

- **Operational:** The student's ability to use hardware and software.
- **Informational:** The capacity to search, select, and process information via technology.
- **Strategic:** The ability to use technology to attain particular goals.
- **Productive:** Formal and complex skills, such as taking an online course or visiting websites that enhance the political, cultural, and knowledge capital of users (e.g. financial and health websites) (van Deursen and van Dijk, 2010)

The notion of the 'digital native' has resulted in an erroneous assumption among many in education that young people are intrinsically tech-savvy and need no preparation in technology use. However, research shows that even when students may have strong operational skills, their informational, strategic, and productive skills are often relatively weak. This is particularly true for students (and adults) coming from homes with lower levels of income and education.

Studies in Chile (Correa, 2015) and the Netherlands (van Deursen and van Dijk, 2010; van Deursen and van Dijk, 2014) demonstrate that students from poorer households or households with less educational attainment consume less information, read less news, use social media sites more frequently, and use simpler applications for communication and entertainment (van Deursen and van Dijk, 2014). Those from higher socioeconomic status with higher educational attainment use more advanced applications of the web for informational, educational, communicational, or service-oriented purposes (van Deursen and van Dijk, 2010; 2014). When they do use social media sites, such as Facebook, they do so in more 'potentially beneficial ways' (Correa, 2015, p. 9) than their less wealthy and less educated counterparts.

Even though students may be frequent users of technology, 'digital inclusion' is a far more complex and multifaceted concept involving a continuum from consumption activities to active and creative uses (Correa, 2015). A major challenge for education systems is to ensure that economically disadvantaged students are provided with educational opportunities that close this usage gap, so these students develop the full range of technology skills that drive productive educational uses of technology.

Box 12: *The usage gap*

Support includes access to both external expertise and peer expertise, as well as exposure to school-based models of teaching successfully with technology in student-centred ways (Ertmer, 2005; Li and Choi, 2014; Hord et al., 2006; Burns, 2011; Dimock et al., 2001; Burns, 2007; B. Avalos, personal interview, June 2021). So important is this collegiality and reciprocity that Li and Choi (2014), in their study of technology adoption in Hong Kong schools, suggest that the social capital of a school has a stronger direct effect on changing teacher behaviours and beliefs than does access to professional development.

2.3.3.4.4 SYSTEMIC BARRIERS

National curricula and national assessment systems play a disproportionate role in teachers' ability to successfully integrate technology to support student centred learning and higher-level thinking. These systemic barriers deserve special mention.

National curricula are often formidable barriers to technology integration and higher-level uses of technology. Curricula may not reflect the academic and professional skills needed by students to compete in a global workplace. They may not emphasise STEM subjects or equip students with the necessary knowledge and skills to solve difficult problems. They may not help students make sense of information they receive from varied print

and, increasingly, digital media sources; develop higher-level digital skills (such as those as noted in Box 12) or prepare students for a workforce where success results not just from what, and who, one knows, but what one is able to do with that knowledge.

Many national curricula emphasise rote learning and the use of technology for decontextualised 'skills' that are more easily assessed in national exams. While it is important to have good operational skills, more important is using technology in ways that equip students with the skill sets they need for work and for life, such as using technology for strategic and productive purposes (noted in Box 12). However, this requires outcomes-based or competency-based curricula and student-centred approaches that allow for more authentic uses of technology. Unfortunately, even where there have been ambitious curriculum 'big idea' reform efforts, such as competency-based curricula and student-centred instruction, in countries such as South Africa, Rwanda, and Kenya, many of these big idea reforms have had limited impact on teaching and learning, including authentic uses of technology (Fleisch et al., 2019, pp. vii, x).

Second, national assessment systems create bottlenecks and barriers in terms of student development within the secondary system. National examinations often present an opportunity cost in terms of preparing students for the world of work. Teachers often regard these assessments, not as markers of student achievement but as accountability measures of how faithfully they follow the national curriculum, and thus 'teach to the test.' Instruction and measurement as part of such systems may do little to help students develop work-readiness skills or strategic and productive digital skills (outlined in Box 12). Instead, the focus of day-to-day teaching becomes exam preparation, particularly in higher grades, with a commensurate focus on lower-level skills such as recall, identification and comprehension versus higher-level skills such as analysis, creation and problem solving. This is particularly true where high-stakes examination systems, such as 'leaving school examinations,' like the Baccalaureate and the General Certificate of Secondary Education, prevail (Mastercard Foundation, 2020).

2.3 TECHNOLOGY FOR LEARNING: ADDITIONAL AREAS FOR RESEARCH

Section 2 has focused on research that specifically outlines benefits for classroom uses of technology, assessment, and the critical supports for and the barriers contravening effective uses of technology for learning. The variety of reported results—across countries, grades, assessment types, outcome measures, implementation years, usage, and objects of study (hardware vs. software vs. instruction)—emphasises the external validity challenges around technology in education research and the difficulty in determining why some technology-based initiatives appear to succeed while others fail.

There is no body of longitudinal evidence showing that technology in and of itself drives fundamental improvements in student learning. Rather, research suggests that effective use of technology is a complex process with numerous building blocks that must be in place for technology to have any chance at improving student learning outcomes. These include equitable access to basic infrastructure; teacher characteristics and skills; the availability, frequency and quality of professional development and support for teachers and school leaders; organisational support and pressure with mandates for change and a culture of risk-taking and experimentation; and alignment with national curricula and assessment systems. These supports are not optional—they are obligatory.

As readers of Section 2 have undoubtedly noticed, the research on educational technology is often uneven. For example, while there appears to be much early-stage research aimed at developing new forms of educational software, content, and products, there are fewer empirical studies designed to determine which approaches of technology use are most effective for student learning. Most research shows more positive effects of educational technology for older, versus younger, learners, although as discussed in this section, there are studies showing that technology has very strong learning benefits for younger children, too (Kizilcec et al., 2020).

More important, even when and where research is conducted and study results published, effect sizes and statements about statistical significance may hold little inherent meaning for policymakers, principals, teachers, and perhaps even readers. Although rigorous evidence-based research is essential, the statistical representations of the findings they generate often provide little insight into the actual meaning and magnitude of those effects. Many of the statements about technology's benefits in this section can only point to the 'what' and 'how much'—not the 'how' or 'why.' Statistical significance thus may not necessarily confer any degree of practical or meaningful significance. To derive deep understandings of the drivers of effective versus poor uses of technology and to make that information resonant, the educational technology research community will need to embrace and value rich, descriptive qualitative research as much as it does rigorous quantitative research.

Taken together, these comments point to the need for additional high-quality, methodologically diversified, and contextually targeted research. Clearly, numerous issues about teacher professional development, personalisation, hardware provision, etc. have been raised in this section, offering potentially unlimited areas for further research. Section 2 concludes, however, with recommended research questions that focus on the two Achilles' heels of educational technology initiatives—quality and equity. These questions are outlined in Table 3.

Category	Suggested Research Questions
Quality	• What specific pedagogies or instructional approaches—for example, feedback, small-group work, self-paced learning—work best with specific technologies? • What are the most important characteristics of effective teacher professional development and support and how are these characteristics directly linked to improved teaching with and without technology? • Which large-scale assessments can measure cross-cutting skills and higher-level thinking associated with a particular domain (e.g. as in the US's *Next Generation of Science Standards*)? What characteristics do these assessments share and how can they be introduced in LMICs?
Equity	• Can technology improve learning for the world's poorest students? If so, which technologies and under what conditions? (Lynch, Singal and Francis, 2021). • What are the effects of different types of technology applications on particular types of students (e.g. limited national language proficiency, special education, gifted and talented)? • Does educational technology have more positive learning outcomes for older or younger learners?

Table 3: *Suggested questions for additional research (Section 2)*

Technology can serve as a learning tool, but it also serves as a tool to deliver learning. Although similar issues of quality persist, it is as a delivery system that technology's reach and ability to scale are more tangible and measurable. Technology as a delivery system for learning, in particular, via distance, is the focus of the next section of this think piece.

SECTION 3: TECHNOLOGY TO DELIVER LEARNING

In addition to technology as a learning tool in and of itself, a second important function of technology is as an educational delivery mechanism to provide learning to students or teachers (in the form of professional development). In this model, the student is learning *through* technology. The teacher directs learning and, depending on the exact modality (radio, online, etc.), may also be the person directing the use of the technology.

Section 3, therefore, focuses on technology for instructional delivery, primarily via distance, where the teacher and student are separated by time and place and where formal learning may not occur within a school or classroom. This section acknowledges up front that the increased movement of content and learning to the cloud makes notions of 'in-person' versus 'distance learning' more fluid and that the modalities noted in Section 3 could also find a home in Section 2. Yet as noted in Section 1.3, the definitions of place-based and distance technologies have blurred. For instance, traditionally categorised distance modalities, like online learning, can occur where the teacher and student are separated, or when they share the same physical space, such as online learning as part of a blended system.

3.1 TEACHING VIA TECHNOLOGY

Teaching via technology has typically occurred when the teacher and student are separated by distance or in contexts where there are no teachers or the person serving as the classroom teacher is untrained or poorly trained. In such contexts, the delivery of learning via technology has been classified as *distance learning*. Keegan (1996) defines distance learning as a planned learning experience or method of instruction characterised by quasi-permanent separation of the teacher and learner(s). Within a distance education system, instruction occurs through various analogue and digital modalities, such as television, radio, and more recently mobile learning and online learning. Traditionally, in such cases, the teachers or educators design learning experiences that match the technology delivery system in order to provide instruction to students.

Any discussion of distance learning or education must begin with the acknowledgement that teaching *via* technology (separated by time and space) can be fundamentally different from teaching *with* technology (typically, in-person learning) This distance, and attempts to overcome it via technology, both facilitate and constrain every element that is part of the teaching and learning process—content, design process, means of communication, materials used, classroom management, pedagogy, assessment, and above all, how teachers teach and how and what learners learn.

As such, distance education demands a new set of complex skills for those teaching in such modalities. Teachers must learn how to use the technologies themselves, select and create content, design for and develop pedagogies that best match a particular technology delivery system. In particular, teaching via online learning injects into the learning process a bifurcated instructional approach not typically present in face-to-face learning or in other distance modalities—the notion of synchronous and asynchronous learning.

3.1.1 ONLINE LEARNING

Online learning is learning that is delivered almost entirely or mostly over the internet through web-based courses, classes, or interactions. An online learning experience essentially virtualises the face-to-face learning experience: students access digital content, interact with their teacher and classmates, discuss and take tests, and do homework but all through some type of internet-based platform.

That was the easy part. Now it gets complicated.

Before discussing online learning in greater detail, three foundational concepts are critical for moving forward. These are:

1. **Synchronous vs. asynchronous learning.** Asynchronous learning involves students learning at different times and in different places. With synchronous learning, students learn at the same time but in different places.

Virtual schools, or cyber schools, are one of the fastest-growing subsets of web-based learning for students and teachers. These schools are full-time online learning programmes in which learners enrol and receive credit. As in brick-and-mortar schools, students must fulfil all course requirements, complete assigned readings, participate in discussions, turn in assignments, and take tests—all online. Teachers design content, communicate with students, provide lectures, answer questions, check for understanding, grade projects, and assign grades—all online (Molnar et al., 2021). Virtual high schools have proliferated throughout the United States, with 477 full-time virtual schools in 35 states, enrolling 332,379 students (2020 data) (National Centre for Education Statistics, 2021).

Along with virtual schools, the United States in 2020 counted 306 blended schools enrolling 152,530 students (National Centre for Education Statistics, 2021). One of the oldest and most successful of these is the Florida Virtual High School, a fulltime online high school. Outside the US, Dubai's Digital School is an example of a *part-time* virtual school. It offers classes three days per week online to 20,000 refugee students.

Open universities are distance education universities that combine various forms of distance technologies with some face-to-face instruction to provide learning opportunities to non-traditional students (students over 21, working professionals, etc.). They are open to all learners, hence the designation *open university*. One of the most well-known is the United Kingdom's Open University, which was founded in 1969 as the University of the Air (Burns, 2011, p. 13).

Open universities pre-date virtual schools. They were established in earnest in Asia in the 1980s in order to educate Asia's young population, many of whom were graduating from secondary school with skills that did not equip them for the world of work. Because of their large size—enrolling tens of thousands of learners simultaneously—open universities have been christened *mega-universities* and are often the main source of tertiary education in their countries. Among the largest open universities are Indira Gandhi National Open University (India), Anadolu University (Turkey) and Universitas Terbuka (Indonesia).

Box 13: *Virtual schools and open universities*

2. **Cohort-based vs. self-paced courses.**

Cohort-based courses are online classes with a group of 'classmates' who follow the same curriculum and participate in the same activities. Cohort-based courses offer less flexibility and more structure, and they typically combine synchronous and asynchronous learning (with perhaps more emphasis on the former). Self-paced courses involve students working alone at their own pace and are typically asynchronous. They offer more flexibility and less structure.

3. **Teacher led vs. self-paced courses.**

Teacher-led courses are led by a teacher.[29] They can be synchronous classes, asynchronous classes, or a blend of both. Most self-paced courses are asynchronous courses, with either no teacher or pre-recorded video 'teacher.' One example of the latter is a Massive Open Online Course (MOOC).

These sets of terms are not completely dichotomous. For example, a teacher-led, cohort-based course can be synchronous and asynchronous, and students can work alone or with others in a self-paced course. However, these terms are noted here because they have design, instructional, and research implications, which will be discussed later in this section.

Since the development of web-based or online learning over the past two decades, numerous factors have converged to drive its growth, primarily at the upper secondary and tertiary levels of the education system. These factors include increased internet access; global adoption of the internet; a desire, particularly for those balancing higher education with work, for more flexible learning opportunities; intensifying demand for a workforce prepared for the demands of a knowledge economy; and the eternal desire to use technology to fix struggling or underfunded educational systems. As such, online learning has increasingly been viewed as an integral and necessary mode of education delivery. This has resulted in greater adoption of online courses as part of 'brick and mortar' schools, particularly universities; shifts to online modalities within open universities; and, in places like the US, the growth of virtual or cyber schools (See Box 13). (Molnar et al., 2021; Burns, 2016; Sloan Consortium, 2012).

29 Thus far, 'teacher' has been used to designate those teaching at the pre-school, primary and secondary levels. In this section, because so much online learning occurs at the tertiary level, the term, 'instructor' is used to designate teaching at this tertiary level.

However, the additional prominence and popularity of online learning has truly accelerated in the last several years as a result of two phenomena: the development and expansion of Massive Open Online Courses (MOOCs) and the COVID-19 pandemic.

The impact of COVID has been particularly, and unexpectedly, profound. For millions of students, particularly in upper secondary and tertiary institutions, remote learning, often via online classes, became, and still may be, the only channel for continued formal education during COVID-19. Online learning and its various 'mutations'—hybrid, HyFlex and IFlex—have become part of many national educational recovery efforts and are allowing students to re-engage incrementally with in-person learning as health conditions permit (See Table 4).

Although their benefits are far from even or equitable, it is hard to overstate the explosion in online learning as a result of the COVID-19 pandemic. In the Americas and Europe, 72% and 85% of higher education institutions replaced face-to-face teaching with online classes compared to 60% and 29% for Asia/Pacific Region and Africa, respectively (International Association of Universities, 2020, p. 24). In just one year, from 2019 to 2020, major MOOC providers—Coursera, EdX, Future Learn, and Class Central—reported growth rates of 150%, 60%, 207%, and 114%, respectively, in new registered users (Institute of Electrical and Electronics Engineers, 2020). These growth rates and numbers may not be self-sustaining, but they indicate that millions of learners were exposed to online learning, possibly for the first time in their lives.

3.1.1.1 THE SEGMENTATION AND DEFINITIONAL VARIABILITY OF 'ONLINE LEARNING'

Before the COVID-19 pandemic, the terms associated with online learning were fairly fixed. *Online learning* largely meant asynchronous learning that occurred within a learning management system (LMS). Web-conferencing tools, such as Zoom, were often secondary to the LMS as the main learning platform and learning almost always occurred away from a physical school setting. Indeed, *online learning* implied the substitution or replacement of a traditional face-to-face learning experience.

Again, rapid developments in internet-based technologies, and the COVID-19 pandemic, have blurred these fixed definitions of online learning. Online learning has evolved from being one thing to being a set of variations on a theme, with increasingly distinct blended or hybrid variants.

This evolution has spawned a great deal of flexibility, choice, and opportunity for online learners. It has also, as Table 4 illustrates, resulted in a good deal of semantic variability—and confusion—when it comes to online learning. Online learning has evolved from being a certain type of learning with defined characteristics, to any learning in which we engage fully or partially online, in school settings or outside of them, with others or alone, at the same time or at different times, collaboratively or individually, and with any array of digital and analogue tools. Table 4 explores some of these variants.

Online Learning Variant	Characteristics
Remote Learning	• Coined during the COVID-19 school closures, remote learning is emergency and temporary distance learning. In countries with good internet infrastructure, remote learning essentially equalled online learning. In many others, it meant distance-based technologies, such as radio, TV, and phone-based supports, with and without online learning. • While many of the world's students were introduced to remote learning during COVID-19, for millions of children in countries such as, Côte d'Ivoire, Lesotho, Kiribati, Sudan, The Gambia, Guinea-Bissau, and Mauritania, where only 3% of rural learners on average had access to electricity, there was no remote learning of any kind (Dreesen et al., 2020, p. 4).
Blended Learning	• A formal education programme in which a student learns *in school*, at least in part, through online learning. • It involves some element of student control over time, place, path, and/or pace (Christensen Institute, 2021).
Hybrid Learning	• Now rebranded, hybrid learning is no longer synonymous with blended learning as it once was. It has evolved into an education delivery model that involves a mixture of *in-school* and *online* teaching and learning options. • It is a *sequential* model—with some learning occurring at home preceded or followed by some learning occurring in schools. • Traditional 'dual mode' universities, such as the University of the West Indies and the University of Queensland (Australia), were some of the first hybrid universities, allowing students to pursue degrees either on campus or via distance.

	• Even prior to the COVID-19 pandemic, more hybrid universities had taken root, offering 'flexible degree programmes' that could be packaged and bundled to meet the needs of current and future learners preparing for workforce needs (The European Consortium of Innovative Universities, 2021).
HyFlex	• This is a variation of hybrid learning where learning is simultaneously delivered online *and* in-person. This model was often used in schools during the COVID-19 pandemic to enable social distancing by having some students in person and some online from home at the same time. • Students can choose to attend virtually or in person on any given day, based on health requirements, preference, or content being covered in class. • This is a *simultaneous* and *synchronous* model of learning. Both in-person and online (virtual) classes occur *at the same time.* • This option is most often used at the university level and in schools that can afford the necessary infrastructure (360-degree cameras, microphones, robust high-speed bandwidth) that make this possible (Fleming, 2021, p. 2). • In a HyFlex model, students have full control of their modality (face-to-face, online synchronous, or online asynchronous (Irvine, 2021, p. 46).
I-Flex	• In an I-Flex model, all students attend school in person for 3–4 days per week. During this time, learning is *blended.* • The other 1–2 days per week are 'intervention days,' during which students who have been selected for intervention attend in person. • Intervention groups are flexible and can be reconfigured at intervals (e.g. monthly, by quarter), so that students who need the most assistance with the current course content are provided intervention support (Fleming, 2021, p. 2).
Bichronous Learning	• This is a combination of asynchronous and synchronous online delivery methods. • Students participate in anytime, anywhere learning during the asynchronous parts of the course. • They then participate in real-time activities for the synchronous sessions. The amount of the online learning blend varies by the course and the activities included in the course (Martin, Polly and Ritzhaupt, 2020).

Table 4: *Variations on a theme: The many faces of online learning*

The above modalities and variations of online and blended learning have facilitated improvements in overall teaching and learning (Mastercard Foundation, 2020). For example, teachers have harnessed technology to provide students with content and support before and after ‘live classes’ (whether face-to-face or via Zoom) and thus appreciate how blending online and face-to-face modalities can extend windows of opportunity for learning (Christensen Institute, 2021). However, these modalities are still evolving and pose numerous funding, design, instructional, and research challenges. They lack the research base of other forms of distance education, and their evolving definitional variability makes comparisons over time challenging.

3.1.1.2 ACCESSING ONLINE LEARNING

Online learning is typically delivered via a number of platforms. Table 5 outlines some of the basic attributes of these; however, the table is not exhaustive, and a few thoughts should frame interpretation of Table 5. First, as noted in Section 2, as software increasingly resides in the cloud, online learning becomes arguably much broader and more diverse than presented in Table 5. Other online activities, not noted in Table 5, may also constitute online learning— for example, watching YouTube videos to gain a particular skill.

Second, online learning is still largely the province of older learners, so there are very few LMS or MOOCs for primary age students. (Seesaw, a portfolio based LMS, is one exception.) Third, many of the platforms outlined in Table 5 are often integrated with one another. For example, an LMS may incorporate Google Classrooms, third-party apps (i.e. stand-alone websites), HyperDocs, choice boards, and/or a web-conferencing tool. Web-conferencing tools can contain links to HyperDocs and playlists and integrate stand-alone websites as apps within the web-conferencing platform itself.

Fourth, each platform demands specific pedagogies, particularly in the case of asynchronous platforms or activities where little attention is often paid to pedagogy. Finally, MOOCs, online courses, and webcasts may be often accessed more by learners who are outside the formal education system or professionals, such as teachers.

Platform	Examples	Audience	Features	Types of Learning It Supports	Advantages	Drawbacks
Learning Management System (LMS)	Hundreds. Examples: • Moodle (open source) • Canvas (proprieta ry	• Secondary • Tertiary • Adult learners • Teacher professional development	Includes: • Content-management component • Administrative component (reporting) • Data component (learning analytics) • Communication component (email, SMS, discussion forums) • Assessment component (tests, portfolios) • Instructional component	Synchronous Asynchronous	• Centralised: Organises all online learning in one place. • Virtualises the classroom or the school. • Secure • Closed system with strong security.	• Cost • Learning curve can be steep. • Even when free, tools like Moodle involve upgrades, updates, maintenance, etc.
Massive Open Online Course (MOOC)	• EdX • Coursera • Udacity	• Tertiary • Secondary • Adult learners • Teacher professional development	• All the features of online courses, but they are ***massive*** (hundreds or thousands of students) and ***open*** (i.e. anyone can enrol). • For that reason, there's no live teacher and learning via MOOCs is self-paced.	Asynchronous	• Makes learning, especially in STEM subjects, available at low or no cost. • Allows for 'buffet'-type learning. Learners can pick and choose what they want from a course and drop in and out as desired. • Users can take courses from top-flight universities.	• High rates of attrition—the majority of learners do not complete courses. • Video-based so often bandwidth intensive. • Pedagogy is often highly didactic and traditional.

Web-Conferencing Platform	Dozens. Examples: • Zoom (commercial) • Big Blue Button (open source)	• Primary • Secondary • Tertiary Adult learners (webcasts) • Teacher professional development	• Supports real-time, face-based meetings, conference, training, or classes (webinars) among people in different locations. • Meetings can be recorded and viewed later (webcasts). • Supports integration of native or third-party tools to make learning more interactive (e.g. jamboards, polling software).	Synchronous	• Simulates a classroom setting in that is 'face-based' and instruction is real-time. • Can support more interactive instruction.	• Highly bandwidth intensive. • Can be taxing to be online and live ('Zoom fatigue').
Online Classrooms	Google Classrooms	• Upper primary • Lower secondary • Secondary	• Google Drive overlaid with Google Apps for Education, Chrome extensions, and a calendar. • Students complete assignments and return to teachers for a grade.	Synchronous Asynchronous	• Free with a Google account. • Essentially a folder structure for keeping classroom and learning materials. organised • Numerous apps and extensions can make learning more synchronous and collaborative.	• Limited capabilities on its own, typically integrated with other tools. • Privacy issues • Further locks teachers and students into one technology company's universe. • Without real efforts to use Google extensions and different pedagogies, can reduce learning to series of uploading and downloading assignments.
Teacher-Created	• Choice boards • HyperDocs	• Upper primary	• Self-contained lessons on a particular topic or set of tasks.	Synchronous Asynchronous	• Low bandwidth—assignments can be shared via email.	• Need other supports (rubrics

Online 'Platforms'	• Web Quests • Playlists	• Lower secondary • Secondary	• Typically designed for self-paced learning. • Created according to an instructional framework (e.g. the 5 E model).		• Allow, more personalised learning. • Self-paced does not necessarily mean students work alone. • Students can complete HyperDocs and choice boards online or off, alone or with classmates.	for grading, assessment, etc.). • 'One off' in that, each teacher creates his/her own content. • Less scalable than other platforms.
Stand-Alone Websites	Thousands. Examples: • Web 2.0 tools (e.g. Edmodo) • Multimedia tools (e.g. Nearpod)	• Primary • Secondary • Tertiary • Teacher professional development	• Can be knowledge tools, assessment tools, etc. (Click here for categorisation and exploration of examples) • Work together with LMS and web-conferencing platforms or as stand-alone tools	Synchronous Asynchronous	• Lower-cost – Typically low monthly subscriptions. • Don't need to invest in an expensive platform. • Cloud-based so security and updating are handled by vendor.	• Popular, free tools run high risks of being monetised or purchased by for-profit companies. • Need additional supports and integration with existing systems (e.g. grading and reporting).

Table 5: *Platforms for online learning (Click on links to see specific examples)*

3.1.1.3 ONLINE LEARNING'S BENEFITS

Online learning, when designed well, offers numerous benefits. These include scaling education; introducing technology-based learning to students; offering access to multimodal types of content and learning; and mitigating the effects of teacher absence (Olson et al., 2011). While technology cannot replace a fully functioning education system, online learning is increasingly utilised to provide curriculum-based education to primary and secondary school-age refugees as well as to their teachers (UNESCO, 2018; Culbertson et al., 2019; Mastercard Foundation, 2020).

These general benefits acknowledged, this think piece examines the two main categorical benefits of online learning: its replacement value and its enhancement value.

Replacement Value. Online learning can function as a *replacement* for face-to-face instruction, particularly in cases where the latter is too costly or is logistically impossible to carry out successfully (Means et al., 2009). When discussing the Global South, however, the replacement value of online learning assumes an even more existential importance. Simply put, for many learners across the globe, online learning and the internet provide access to experiences, resources, and interpersonal professional interactions *that would be otherwise inaccessible* in a non-networked environment (Burns, 2011). This access is particularly valuable for traditionally underserved groups and teachers in remote geographical areas, where face-to-face professional development would be impossible. (One example is UNICEF's Learning Passport.)

Online learning's replacement value has been most obvious during the COVID-19 school lockdowns as students across the globe turned to formal online schooling. For students, particularly older ones, in countries with limited or no formal online education, numerous online initiatives stepped in to fill the schooling void. For example, the MOOC provider Coursera[30] provided free access to 3,800 courses for 50,000 learners in each jurisdiction (defined by a particular government) (Coursera for Campus, 2021). The Global Education Coalition (GEC), organised by UNESCO, mobilised multilateral donors, private technology companies and public and non-governmental educational organisations to leverage digital content, online courses, and other teaching and learning aids for access by millions of students not attending school (United Nations Educational, Scientific and Cultural Organization, 2020a).

As a result of the New York Declaration for Refugees and Migrants, adopted by the United Nations General Assembly in 2016, increased effort has been made to extend education to students in

30 Coursera is an online consortium of 245 partners (mainly universities) across 54 countries. Some of its university partners include some of the Indian Institutes of Technology, as well as Erasmus University, Stanford University, Imperial College of London, and the National University of Singapore.

refugee contexts, particularly in Sub-Saharan Africa and the Middle East. Governments; international agencies, such as the UNHCR; university consortia; and private education companies have harnessed online learning to improve access to education for refugee children, adolescents, and teachers (United Nations High Commissioner for Refugees, 2018). For example:

- At the Dadaab refugee camp in northern Kenya, the Centre for Interpreting in Conflict Zones at the University of Geneva offers MOOCs for Somali refugees, including ‘Foundations of Teaching and Learning’ for current and prospective teachers (Université de Genève, n.d.).
- The Africa Higher Education in Emergencies Network offers a diploma degree programme for the Diploma in Teacher Education in Emergencies (Africa Higher Education in Emergencies Network, n.d.).
- In Chad, Kenya, Lebanon, and Niger, the Carey Institute for Global Good’s online courses instruct refuge teachers in creating open educational resources (OERs) in Arabic, English, and French as part of its Refugee Academy Network, and a number of MOOC providers, such as Coursera and ClassCentral, offer free online MOOCs for refugees (Carey Institute for Global Good, 2021; MOOC List, n.d.).

Access to learning is a good thing—*if* online students are actually learning from all of these opportunities. This points to the challenge of how the success of this replacement value should be considered and interpreted. On the one hand, the key measure is *equivalence.* Means et al. (2009) argue that if learner outcomes are the same whether a course is taken online or face-to-face, then ‘online instruction is … successful’ (p. 3). The alternative view is that the very availability of and access to these courses themselves, particularly in difficult-to-reach areas and/or with difficult-to-reach populations, *ipso facto* constitutes success.

There is research arguing for *equivalence* in terms of online and in-person learning. A 2009 meta-analysis of research on online learning from 1996 to 2009 showed that, on average, online learners performed modestly better than those receiving face-to-face instruction (Means et al., 2009, xiii). The overall finding of this examination was that classes with online learning (either completely online or blended) on average produced stronger student learning outcomes than classes with solely face-to-face instruction (.20 mean effect size) (Means et al., 2009, p. 18, xiv). The research notes that the observed advantage for blended learning conditions is not necessarily rooted in the media used *per se*, but rather reflective of differences in content, pedagogy, and learning time. These results are in keeping with other research suggesting that online courses can be as good as comparable in-person courses and that blended learning may actually provide a qualitatively superior form of teacher professional development than either online or face-to-face learning alone (Acosta et al., 2021; Zhao et al., 2005; Burns, 2013b).

Enhancement Value. A second benefit of online learning is as an *enhancement* of the face-to-face learning experience (i.e. online learning activities that are part of a face-to-face professional learning experience as in a blended learning or hybrid schooling approach). Given the technological developments associated with online learning (e.g. adding virtual reality experiences to courses), enhancement should take into consideration the improved interactive and communicative approaches that may promote the development of skills that might be harder to develop without technology (e.g. 21st-century skills).

As with the replacement value of online learning, the measurement challenge is in part philosophical. On the one hand, Means et al. (2009) argue that as an enhancement activity, online learning should produce outcomes that are not 'simply equivalent, but measurably *superior to* those resulting from face-to-face instruction alone' (p. 3). Only then, the line of thinking continues, is online learning worth the time and resources. The competing view is that though online learning's outcomes may not be equal to those of face-to-face learning, online learning may in fact be worth the extra time and resources because of the additional, albeit non-measurable, benefits it offers—21st-century skills such as persistence, problem solving, improved written communication skills, digital literacy, mastery of certain kinds of technology, etc. (Acosta et al., 2021; Olson et al., 2011).

Here the data are less clear. For example, virtual schools in the United States, which often claim to provide a superior education than that offered in public schools, have not produced better student outcomes compared to brick and mortar schools. In fact, the opposite is true: many full-time virtual schools have produced measurably worse outcomes (Molnar et al., 2021). And while Means et al.'s (2009) meta-analysis of online learning shows that learners participating in classes with online learning do better than those in exclusive in-person programmes, those effects are 'modest,' making it harder to advocate for the measurable superiority of online learning.

3.1.1.4 ONLINE LEARNING'S WEAKNESSES

Online learning suffers from numerous weaknesses—it can be poorly designed and highly didactic; suffer from flat, non-interactive content and limited engagement and discussion (McMurtrie, 2021); and, given the complete absence of a teacher or classmates, result in a highly impersonal and lonely experience for learners. However, where online learning really struggles, particularly in the case of MOOCs, is in its high degree of attrition (dropping out), particularly in courses that are self-paced, asynchronous, and that lack a teacher (Burns, 2013b). Although attrition rates for online programs are difficult to document, there are data positing that online attrition rates generally exceed those of face-to-face instruction by 10%-20%, with estimates of attrition ranging from 40% to 50% in online programs to almost 90% in many open universities (Holder, 2007; Burns, 2016; Latchem and Jung, 2010).

It is hard to overstate the degree to which attrition threatens online learning as a viable educational delivery mechanism. Lower retention and completion rates are a barrier to more widespread adoption. High rates of attrition, especially as witnessed during the remote learning of the pandemic, undermine the perceived quality, utility, cost-effectiveness, and legitimacy of online learning. Indeed, they undermine the very rationale for online learning and call into question whether it is even worth the investment (Burns, 2011, p. 185).

Like most technology-related issues, there is evidence that attrition does not impact all learners equally and that the equity gaps that persist across the higher education system are also prevalent in online classes (Acosta et al., 2021). For example, attrition rates are much higher among certain groups—students who are poorer, students from the Global South, students who may not have been raised speaking the online course language of instruction, and students who are academically at risk (Olson et al., 2011; Acosta et al., 2021; Kizilcec et al., 2020; Vázquez Toness, 2020; Mitchell, 2020). Indeed, the disproportionately high attrition rates among less affluent groups of students may undermine one of the more compelling arguments for online learning—that it provides equitable access to learners for whom face-to-face learning is not an option.

3.1.1.5 THE MANY REQUISITES FOR ONLINE LEARNING

Developing excellent online courses places many demands on an education system in terms of infrastructure, equipment, content, and design. Above all, it demands much from teachers and students. Education systems are often good at paying attention to technology demands but far less attentive to preparing the most important members of the online learning ecosystem—the online teacher and students.

Preparing Online Teachers. Online learning does not eliminate the need for good teaching; it amplifies it. Online teachers have to do everything face-to-face teachers do—but through and with technology—thus adding one more layer of complexity to teaching itself. Thus, as discussed in Section 2, online teachers must receive extensive preparation and support, not just in using online technologies, but in *teaching well* through these technologies.

Online teachers need to know how to use the technology and help their students use it. They need to have mastery of content, but more importantly, help learners develop a deep understanding of subject matter via content-appropriate instructional strategies within a technology-mediated environment. This 'technological pedagogical content knowledge' (Harris, Mishra and Koehler, 2009) means teachers must make connections among technologies, curriculum content, and specific pedagogical approaches to produce effective, discipline-based teaching via technology (Burns, 2011, p.177). This level of expertise is difficult to attain.

Possibly the most challenging of the requisites and tasks listed above is establishing a sense of online 'presence.' Presence is a strong and skilled facilitation of knowledge and of the learning process that helps learners become socially and academically integrated in the course, and it is often the most important factor in the online learner's retention in and satisfaction with an online course (Burns, 2011, pp. 177–178). While Artificial Intelligence and digital teaching assistants (to be discussed in Section 4) are increasingly being deployed to mimic teacher presence in online learning, as witnessed during remote learning, most learners still prefer live teachers to computer avatars.

Preparing Online Learners.[31] Students, too, particularly as witnessed during the pandemic, need help successfully learning online. There appear to be generally three sets of characteristics that distinguish successful online learners (those who complete all of the requirements of an online course of study) from unsuccessful ones (those who do not complete their course). Success in online learning is a result of the interplay of these three sets of characteristics.

The first are *personal traits*, such as autonomy, self-regulation, self-direction[32] and being goal oriented. The second are *skills associated with online learning*, including time management and the ability to read and writing online, as well as the student's prior history in taking and completing an online course. Third are *course/program-related variables,* such as access to technology, support, and materials; learner engagement and interaction with other learners; and a student's sense of connection or isolation.

Positive student perceptions of the teacher regarding the responsiveness, frequency, and quality of communication and feedback are also linked with successful online completion. Course design and delivery modes (synchronous versus asynchronous; self-paced versus cohort-based; and teacher-led

31 The following five paragraphs are modified and adapted from Burns, M. (2019). Staying or leaving? Designing for persistence in an online educator training program in Indonesia, pp. 142-143. Open Learning: The Journal of Open and Distance Learning, 28, 2, 141-152. Used with permission of Taylor & Francis Group.

32 Self-directed learning has been previously referenced in this think piece. In self-directed learning, learners choose to initiate their own learning, diagnose their own needs, formulate learning goals, implement learning strategies, and evaluate their own efforts and outcomes (Knowles, 1975). Self-regulation is the ability to organise one's emotions, behaviours, and thoughts in pursuit of attaining a long-term goal. It encompasses self-control and self-efficacy (a belief that the learner can succeed if they try) and three 'phases' of activity: forethought, a focus on performance, and reflection (Zimmerman, 2011).

versus self-paced) can influence the learner's sense of either connection or isolation to the teacher, institution, or learning group (Zimmerman, 2008; Lapointe and Reisetter, 2008; Hart, 2012; Aragon and Johnson, 2008; Park and Choi, 2009, cited in Burns, 2013b, p. 142).

All of these variables—those related to the personality of the online learner, to the course itself, and to the nature of online learning—are highly interconnected and impact a student's 'readiness' to be a successful online learner. Students with low readiness (who have never taken an online course, who do lack good time management skills, who do not read or write well, or who do not enjoy ubiquitous access to technology) are more likely to drop out of an online course. In contrast, students with a high degree of readiness (who are autonomous learners, with strong technology skills, and who have strong information management skills) are more likely to persist in an online course. The design of an online course—whether it's teacher-led or not, cohort-based, or synchronous or asynchronous—can mitigate or exacerbate these characteristics (Burns, 2013b).

Thus, online learning programs need to help learners develop a range of technology skills to not only navigate the course but more importantly to complete assignments, conduct research, critically evaluate information, produce academic products, and communicate with peers. Online programs must help students *plan* for learning—i.e. learn how to make a schedule, coordinate with others on assignments, set and follow through on goals, and avoid distractions (Burns, 2013b). This plan making has been shown to be particularly important in alleviating some of the effects of attrition in online learning (Kizilcec et al., 2020).

3.1.1.6 RESEARCH IMPLICATIONS FOR ONLINE LEARNING

The discussion on online learning concludes with a nod to the research challenges associated with this educational delivery modality. Online learning, particularly through LMSs, generates a good deal of back-end data (logins, time on task, downloads, and discussion posts) that can support research. Online courses have well-defined outcomes (course completion, grades); and student progress is continuously tracked through a common platform (Kizilcec et al., 2020). The rich quantitative and, in many cases qualitative, data resulting from LMS design features and activities (like discussions) can be analysed for programme improvement, evaluated for worth, and researched to further improve inputs and outcomes in online learning.

Yet, as discussed throughout this section, online learning is defined by its heterogeneity. Online learning, like technology itself, is not a uniform intervention; it is multifarious. It varies in *how it organises instruction* (100% online, blended, hybrid, HyFlex, I-Flex, or web facilitated); in its *delivery* (synchronous, asynchronous, or bichronous); in the *platforms* used (LMS, stand-alone software, online classrooms, choice boards, HyperDocs, YouTube, social media sites, or as part of a virtual school or open university); in its *scale* (from a student accessing an email from a teacher to cohort-based classes with 20–30 students to MOOCs with thousands of learners); in *formats* (class, course, meeting, micro-courses); *content* (text, games, simulations, multimedia, videos, and audio); and in how it is *accessed* (laptop or desktop, smartphone, tablet, or gaming console).

This heterogeneity may pose implications for research. For instance, are researchers comparing apples and apples or apples and oranges if one group of students is learning synchronously and another asynchronously? Does the design and delivery of a particular online learning modality impact learning outcomes differently? Is the technology influencing the intended constructs researchers want to measure? Is the quality and intended learning of an online program differently impacted by the hardware on which it is accessed (a phone versus laptop)? At the very least, these questions are worth consideration.

3.1.2 MOBILE LEARNING

The most common device or hardware in schools across the globe is that which is often most conspicuous by its absence from classrooms—mobile phones. Despite the fact that 62% of the world's population owns a mobile phone (Statista, 2021), various educational jurisdictions—Ministries of Education in China and France and provinces, states, and schools in Canada, Australia, the United States, and the UK, among others—have formally banned mobile phones from the classroom (Wakefield, 2021). In other countries, such as South Africa, Botswana, and Cape Verde, phones may only be used in class when sanctioned by a teacher on a per-activity basis (Burns et al., 2019b).

From a classroom management perspective, there are certainly numerous valid reasons for limiting mobile phone use in class.[33] However, there are also valid reasons for allowing mobile phones (particularly smartphones) in classrooms as part of a Bring Your Own Device (BYOD) initiative. By 2030, half of the world's youth will live in countries with mobile first or mobile only internet connections (Holon IQ, 2021, p. 42). Smartphones can help reduce the amount of equipment governments must purchase and alleviate pressures on the internet by having students use more

33 Examples include students being distracted from the work at hand, spending time on non-academic or irrelevant sites, taking and posting photos of other students without their consent, real-time cyberbullying, and so forth.

reliable cellular networks. They also contribute greatly to expanding access to educational opportunities in fulfilment of SDG4.

3.1.2.1 MOBILE LEARNING FOR STUDENTS AND TEACHERS

Despite their formal absence from many of the world' classrooms, mobile phones are used extensively in education to furnish students with access to information, experts, experiences, and resources in ways that are affordable and accessible. During the COVID-19 pandemic, national phone-based initiatives (specifically using WhatsApp) in El Salvador, the Dominican Republic, Haiti, and Nicaragua provided students with educational resources and programming (Cobo, Hawkins and Rovner, 2020). Phones have provided tutoring support and access to learning resources for independent self-study for students across Sub-Saharan Africa and for General Certificate of Secondary Education (GCSE) exam preparation through WhatsApp classrooms (Mwareya and Simango, 2021).

In addition to their potential as tools for student learning, mobile phones have been used successfully to provide teachers in Sub-Saharan Africa, particularly in refugee settings, with access to curriculum, language instruction, lesson plans, SMS support, content delivery, virtual coaching, and even their salaries (Burns et al., 2019b). Across swathes of Sub-Saharan Africa, where large coverage and connectivity gaps are often endemic, information and resources are delivered via Secure Digital (SD) cards to teachers in areas that lack access to the internet. In South Africa, where internet coverage is more common, the Department of Basic Education has made core curriculum content available for mobile phones that students can access for pennies per day (Burns et al., 2019b).

3.1.2.2 BENEFITS OF MOBILE LEARNING

Although the research base on mobile phones and improved learner outcomes is thin, a number of experimental studies point to a strong relationship between mobile phones and learning. For example, adults in Niger who received weekly phone calls as part of a two-year education programme improved their math and literacy test scores (0.19-0.22 Standard Deviations)[34] over those who did not receive weekly phone calls (Aker et al., 2012).

34 Because of the heterogeneity of ICT in education studies, many researchers use a standard deviation (SD) to provide a point of comparison across studies and study sites. The SD measures the amount of variance across a set of values. A low SD suggests that the values are close to the mean (expected value). A high SD indicates that the values are spread out over a wider range. For purposes of interpretation, Lipsey et al. (2012) provide a more intuitive interpretation of standard deviations. A 0.10 SD means a student would move

In the United States, low-income parents who received three weekly text messages about their children's academic skills increased their own involvement in their child's learning (a gain of 0.15 to 0.29 SDs). These texts also helped to increase their children's gains in early literacy by approximately 0.11 SDs (York and Loeb, 2018). Finally, in a study of 4,500 families in Botswana with primary school-age children, children whose families received a weekly Short Message Service (SMS) 'problem of the week' saw positive, statistically significant effects (a 0.16 SD gain) on the Annual Status of Education Report (ASER) test. Those who received the SMS plus live phone calls from a teacher experienced gains in numerical skill, on average, of 24% (0.29 SDs) on the ASER test (Angrist, Bergman, Brewster and Matsheng, 2020).

Mobile connectivity is particularly important for refugees. In a 2019 study (Culbertson et al., 2019) consisting of 30 interviews with refugees and/or internally displaced people in Colombia, Greece, Jordan, the United States, and the Maheba Refugee Camp in Solwezi, Zambia, interviewees identified phones as more valuable than laptops or tablets because of their lower cost and greater portability. The adults interviewed reported using phones to learn skills, acquire information, and obtain certifications, while children used phones to keep up with schooling, especially via resources sent through WhatsApp and SMS. Mobile phones also allowed refugees to keep in touch with family and friends, maintain documentation regarding their identity and experiences, and access information and support.

3.1.2.3 CHALLENGES ASSOCIATED WITH MOBILE LEARNING

Although phones are a promising and popular way to deliver educational content and supports to learners, they are no silver bullet. While mobile ownership may be high, relative to laptops or tablets, 56 million learners still reside in locations not served by mobile networks, with almost half of them in Sub-Saharan Africa, and phone subscriptions tend to be concentrated in urban areas (UNESCO, 2020c). The real power of phones lies with smartphones, which are more expensive to purchase and maintain—and even then, smartphones have high interaction costs. It is difficult to read and write on them; not all educational content or websites are designed for smartphones; and 'bite sized' learning may be an attractive option, but it doesn't always equate with quality or depth. Indeed some studies show that students perform poorly on tasks like problem solving when doing schoolwork on phones (Heflin, Shewmaker and Nguyen, 2017). Further, while many countries have

from the 50th to 54th percentile; a 0.20 SD means they move from the 50th to 58th; a 0.30 SD means from the 50th to 62nd percentile and 0.40 SD from the 50th to 66th percentile.

‘zero rated’[35] educational content, learners in other countries may incur (often high) costs in accessing educational content.

Finally, perhaps the most valid reason for eschewing mobile phones as tools for educational delivery, may be their overall harmful effects on students. Using longitudinal PISA data, research appears to causally link increased smartphone use (social media and the internet) to increases in teenage loneliness and decreases in well-being, even when controlling for all other factors. Since 2012, this increase in loneliness has roughly doubled in former Eastern bloc countries, in Latin America, and English-speaking European countries, and increased by 50% in East Asian countries (Twenge et al., 2021). In light of this, and other emerging information on the deleterious emotional and ergonomic effects of too much time spent hunched over phones, one of the best things education systems might do for students, arguably, is limit the time they spend on their phones.

3.1.3 RADIO

Radio—both broadcast and interactive—has been a commonly used model for distance-based student and teacher instruction, primarily in terms of upgrading existing teachers’ content knowledge and teaching skills. In contrast to other technologies, radio ownership exceeds 95% globally, and rates of radio ownership are generally stable between urban and rural households. An estimated 75% of households in the Global South have access to radio; in sub-Saharan Africa, 80%–90% have access to a working radio (United Nations Educational, Scientific and Cultural Organization, 2012).

Across the globe, for decades, governments have capitalised on educational broadcast radio to provide learning opportunities to teachers and students. For example, Botswana’s Ministry of Basic Education broadcasts educational radio programming to primary-age students several times per week. The Government of Cabo Verde has used radio extensively for educational programming and student tutoring. Broadcast radio has been used for teacher professional development in Zambia, India, and Guinea (Burns, 2011). EDC’s *English for Latin America* project uses audio-based dramas, songs, and games to help students in Latin America achieve internationally recognised benchmarks in English. During the current coronavirus outbreak, many Latin American countries turned to radio to provide continuing education to students. During the COVID-19 pandemic, 58% of countries—

35 Digital content, such as certain websites, that is zero rated means that users can access the content without incurring charges to their mobile data plan.

from Lao PDR across Sub-Saharan Africa to Latin America—reported using radio to deliver audio content and continuing education to students (Dreesen et al., 2020).

3.1.3.1 INTERACTIVE RADIO/AUDIO INSTRUCTION

Where radio (and audio) become particularly powerful is through interactive radio instruction (IRI) and interactive audio instruction (IAI). IRI is an instructional approach that uses one-way radio to *broadcast* learning to two audiences: students and their in-class teachers. IAI uses *narrowcasting*—pre-recorded audio programmes delivered via cell phones, CD players, or MP3 players connected to a speaker. Once the in-class teacher turns on the radio or MP3 player, the radio or audio 'teacher' delivers content and directs the in-class teachers to apply a variety of interactive instructional approaches within their classrooms (Burns, 2011).

In this dual-audience, direct-instruction approach, all lessons are pre-recorded. All radio and audio programme content and activities are based on the national curriculum and use a series of scripted and structured learning episodes in which students are prompted to sing songs, participate in individual and group work, answer questions, and perform certain learning tasks (Burns, 2011). IRI and IAI have been used to help students and/or teachers learn content and skills in Sub-Saharan Africa (Guinea, Liberia, Somalia, Cabo Verde, Angola, Mozambique, Guinea-Bissau, Zambia, Zanzibar, São Tomé e Principé, Mali, South Africa, and the Democratic Republic of the Congo); in Asia (Pakistan, Indonesia, Thailand and India); in the Amazon Basin region of South America (Brazil, Peru, Ecuador, Bolivia and Colombia); and in Central America (Guatemala, Nicaragua, Panama, and Honduras) (Burns, 2011; Burns et al., 2019; Inksater, 2017)

Unlike most educational technologies, IRI has a longitudinal body of research from more than two dozen countries documenting statistically significant and consistent improvements in student achievement that is positively correlated with increased exposure to IRI. Pre- and post-studies of IRI programs in Guinea demonstrated improved academic performance for students in Grades 2, 4 and 6 (Creative Associates International, 2002). In Indonesia, in a two-year IAI programme with 6,071 kindergarten students, pre- and post-tests between students receiving IAI programming (the treatment group) and those who did not (the control group) reported that treatment students outperformed control group students on language, cognitive, and physical and psychomotor development (Ho and Thukral, 2009).

Other larger-scale studies also report a positive relationship between increased exposure to IRI or IAI and increased student achievement. South Africa's English in Action programme (1992–2009) focused on improving the English language skills of two million South African students (Potter and Naidoo, 2012). Evaluation data from the programme suggests a positive relationship between increased exposure to IRI programmes and student achievement gains—that is, the more English in Action programmes to which students were exposed, the higher their achievement scores (Leigh, 1995; Potter and Naidoo, 2012).

Larger-scale multi-subject and multi-country evaluations of IRI programmes employing control groups have shown similar positive results. Multi-country and multi-year evaluations of student performance in a variety of subjects (math, science, English, and Spanish) in a variety of countries (Thailand, Bolivia, Honduras, Sudan, India, Pakistan, Haiti, New Guinea, Nicaragua, Zambia, and South Africa) show that students who received IRI instruction did better on assessments in all of these subjects than their control-group peers. Effect sizes ranged from small (.24) in Thailand to medium (.41) in Zambia to large (.94-1.70) in Bolivia, Zambia, Sudan, Pakistan, and India (Ho and Thukral, 2009, p. 21; Tilson, 1991; Corrales, 1995; Leigh, 1995; Thukral, 2016). These learning effects extend to rural students as well. Studies of IRI in Bolivia, Thailand, and South Africa show that the level of achievement among rural students served by IRI approaches or equals that of urban students (Anzalone and Bosch, 2005).

There's much we still do not know about IRI and IAI, however. Many types of educational radio programming, such as tutoring, have not been researched. There is very little research on IRI with older students and how it promotes, not just basic education such as literacy and numeracy, but higher-level, more complex cognitive skills. Although there is evidence from other fields, such as public health, that radio dramas can promote healthy behaviours, as is the case with television, there has been very limited use of radio dramas for educational purposes, an area that warrants further exploration.

3.1.4 TELEVISION

Like radio, television is a familiar and engaging visual medium with expansive global reach—79% of the world's population own TVs[36] (International Telecommunication Union, 2010). During the 2020-2021 COVID-19 outbreak, in what might arguably be characterised as an indictment of online learning, 75% of the world's nations turned to television to provide continuing education to their

36 The ITU's estimate of 79% is from 2010; thus, actual ownership globally is likely much higher. However, unlike radio, TV ownership suffers from an urban-rural divide and varies by region—from 28% in Sub-Saharan Africa to 95% in the Americas and 97% in Europe and the Commonwealth of Independent States (International Telecommunication Union, 2010). Although these numbers may be currently higher than 2010 data suggest, large differences in access to TV still persist.

students. This included many middle-income countries with good internet infrastructure. For example, México and Montenegro used TV to target pre-primary-age children and their families. In the United States and France, state or public TV—the Public Broadcasting Service World program and France Télévisions, respectively, broadcast educational content for lower-secondary students while Morocco and Uzbekistan harnessed accessible TV classes, such as sign language classes, for children with disabilities (Dreesen et al., 2020).

Indeed, television enjoyed an educational renaissance during COVID-19 school closures. But TV in fact has long had a considerable, although perhaps underappreciated, history providing educational opportunities to marginalised learners. In rural schools lacking teachers, programmes such as Telesecundaría and Telecurso have provided in-class instruction to secondary-age students in schools in México and Brazil, respectively. For professional and continuing education, too, television has been used by many of the world's open universities, such as the Open University of the United Kingdom and the Indira Gandhi National Open University (IGNOU), to reach thousands (or in the case of IGNOU, millions) of students learning via distance. Television has also historically played an important role in teacher formation, as exemplified by 'television universities' in China and television-based professional development programmes in Indonesia (Burns, 2011).

3.1.4.1 EDUCATIONAL TELEVISION

However, where television as a tool for educational delivery shines is in terms of educating young learners. Research has long suggested that edutainment—carefully designed educational TV programmes that both educate and entertain—can significantly improve cognitive and school-readiness skills of pre-school-age children (Cooney, 1966). These effects seem to depend on the level of exposure, which is highly dependent on parents' involvement (Watson, 2019).

The most well-studied children's television programme globally is *Sesame Street* (Borzekowski, 2018), created in the United States, distributed via the Public Broadcasting Service (PBS), and currently broadcast in 120 countries.[37] Numerous experimental studies of international variations of *Sesame Street*—in Indonesia, Tanzania, Egypt, Bangladesh, and South Africa—have shown that exposure to *Sesame Street* can result in improved school readiness as well as positive effects on literacy, numeracy, gender-equitable attitudes, and social and emotional development (Borzekowski, 2018; Borzekowski and Macha, 2010; Watson, 2019, p. 43). A larger meta-analysis, synthesising the results of 24 studies with over 10,000 children in 15 countries, examined the effects

37 To learn more about Sesame Street, click here. Access related websites here and here.

of children’s exposure to international co-productions of *Sesame Street* and found significant positive effects in terms of literacy and numeracy, learning about the world, health and safety knowledge, social reasoning, and attitudes towards out-groups. The average effect size equaled 0.29 (Mares and Pan, 2013).

Until recently in LMICs, it was almost impossible to find any studies on the impacts of educational TV that did *not* focus on international variations of *Sesame Street*. However, this situation has been improving. In one of the largest studies on the impacts of educational TV on learning (32,768 children in Grades 3–6 in 516 schools in the Philippines), subject area tests indicated that students who watched the Knowledge Channel, a Filipino-based educational channel, performed better than their control counterparts who did not watch this channel in the five subject areas tested (Gustilo et al., cited in Watson, 2019, p. 44).

Until recently in LMICs, particularly in Sub-Saharan Africa, it was difficult to find local production of educational media, (Borzekowski, 2018, p. 54). This situation is also changing. In 2014, *Ubongo Kids* debuted in Tanzania. Developed by Ubongo, a Dar es Salaam-based producer of educational media content, the programme is now broadcast across 41 African countries in five languages (Ubongo, 2021). Programmes are geared to children ages 7–12. While television remains the primary medium through which *Ubongo Kids* content is delivered, the programme is supported by DVDs, e-books, online videos (accessible via YouTube and *Ubongo Kids’* website), and an interactive app (Watson, 2019). *Ubongo Kids* has spawned a companion programme for children ages 3–6 titled *Akili and Me* (broadcast primarily via television but also available on YouTube).

Watson (2019) found that exposure to Ubongo Kids was significantly and positively associated with mathematics capability among children ages 7–16, even when controlling for age, sex, school enrolment, and Kiswahili attainment. Studies of young children’s exposure to *Akili and Me* have shown results similar to those found in international variations of *Sesame Street*. A four-week comparison study of children who watched *Akili and Me* versus those who viewed other educational content found that the treatment group, even when controlling for their sex, age, and baseline skills, significantly improved their drawing skills, shape knowledge, number recognition, counting, and English skills in just four weeks (Borzekowski, 2018, p. 57).

These studies, along with others (EDC and SRI, 2021; Corporation for Public Broadcasting, 2015) suggest that exposure to educational television can aid learning, and that well-produced television programming can engage hard-to-reach audiences by offering a source of informal education and enrichment. Research further suggests that directing a greater proportion of available educational resources towards educational television interventions may benefit educational outcomes (Mares and Pan, 2013).

3.1.4.2 POPULAR TELEVISION PROGRAMMING

We pivot here to a discussion of two *potentially* promising examples of how television has the potential to positively impact learning for all ages.

First, though 'educational value' might not be the term that springs to mind when considering serialised TV programming, popular TV shows, in particular *telenovelas*, have more quietly proven to be powerful vehicles for changing mindsets and behaviours. In Latin America, where telenovelas are an entertainment institution, they have been credited with agricultural reform; convincing mothers of the importance of childhood vaccinations; improving sexual health, adult literacy, and girls' rights; and lowering female fertility rates (Hegarty, 2012; Inter-American Development Bank, 2009). Most of the telenovelas that have proven so impactful in terms of changing habits or modelling 'pro-social' behaviours have been deliberately designed to do so (see Box 14).

Other types of television programming also have shown positive learning effects. In India, where TV has an extraordinary reach, the Same Language Subtitling (SLS) programme, in 1999, began to use subtitle the Bollywood film songs in a popular Gujarati weekly music programme, *Chitrageet*. The hypothesis driving this experiment was that subtitling mainstream TV content could help illiterate adults and children, who could not be reached by traditional literacy programmes, improve their reading and writing skills. While watching TV, viewers simultaneously matched the on-screen words with the sounds they were hearing. Subtitled words change color to match the audio, making it easy for people to follow along (UNESCO Institute for Lifelong Learning, 2016). SLS proved highly popular. Viewers reported enjoying SLS because it helped them sing along with songs, learn the song lyrics, and write down lyrics for later reference. Research suggested that SLS increased the entertainment value of popular song programmes; enhanced reading abilities; and made reading an incidental, automatic, and subconscious process. Those who watched SLS programming reported higher literacy abilities compared to those who did not watch the SLS programming (UNESCO Institute for Lifelong Learning, 2016).

Thus, the ubiquitous presence of TV in many parts of the globe, even in rural areas, and people's enthusiasm for edutainment that is well-produced, entertaining, and presented in ways where viewers may not even realise they are learning, points to perhaps untapped potential of television programming to improve educational outcomes.

But there is also much to concern us about television, even children's TV. First, as media critics like Neil Postman warned decades ago, TV is excellent at promoting biases and lazy thinking, either by omission or commission (Postman, 1985). The Geena Davis Institute, a US based non-profit research organisation that reports on gender representation in media, has analysed representations of gender, race, LGBTQ+ identity, disability, age, and body size in popular American children's TV shows. It finds that while 62% of children's TV programming have positive representations of girls and women, females, people with disabilities, LGBTQ+ characters, and older people are still under-represented or largely absent on children's TV. And these pernicious biases continue to persist—female characters are still more likely to be sexualised; dark skinned characters portrayed as more violent than white ones; and male characters shown to be more prevalent in STEM fields than female characters (Geena Davis Institute on Gender and Media, 2020).

The Sabido Method is an edutainment design method based in part on social learning theory. It was developed by Miguel Sabido, a TV writer and producer and the former director of the Mexican Institute of Communication Studies. The Sabido Method focuses on creating TV programming that aims to both entertain and educate an audience about a particular issue, create favourable attitudes, shift norms, and promote and reinforce behavioural and social change. It has several clear design elements:

Education focus: Entertainment-education programmes must be designed to educate a very large audience about a particular issue or behaviour (e.g. female literacy)

High production value: The story, narrative, entertainment quality, etc. should be of high quality so the programme enjoys broad viewership.

Strong character development: 'Good' characters are associated with desirable behaviours (sending girls to school) and 'bad' characters are associated with undesirable behaviours (bullying, sexism, etc.)

Clear moral message: Good characters are rewarded and bad characters are punished so the audience is encouraged to imitate positive role models and behaviours (Singhal, Cody, Rogers and Sabido, 2004).

As an example of the Sabido Method in action, in *Ven Conmigo*, a 1970s Mexican TV series, an elderly man graduates from literacy class and, in one episode, reads a letter from his daughter for the first time. As part of this episode, the programme informed the audience about free literacy booklets. The next day 250,000 people showed up to get their copies, and enrolment in the government literacy programme increased nine-fold over the course of a year (Hegarty, 2012).

***Box 14:** The Sabido Method*

Second, edutainment is an area that demands far more research and attention not only to what TV can do in terms of learning but its larger overall effects. Postman's (1985) admonitions about television—the danger of its visual and emotional pull, its dilution of quality information in favor of high entertainment value, and the passivity of the viewer—mean that we may be at a higher risk of 'amusing ourselves to death' and spreading disinformation in an age of 24/7 cable news and streaming TV than at any point since the creation of this medium.

3.1.5 ASSISTIVE TECHNOLOGIES

For many students across the globe—those who are visually impaired, who cannot hear, who have gross or fine motor impairments, or who are aphasic—computer technology and the software and peripherals it supports are often their only link to education. The Convention on the Rights of Persons with Disabilities (United Nations Department of Economic and Social Affairs, 2006), the Incheon Declaration (Education 2030, 2015,) and SDG Target 4.5[38] all aim to ensure equal access to all levels of education for learners with disabilities. As such, many nations have mandated that students with disabilities be provided supports and 'reasonable accommodation' that make learning and school completion possible. One of the most important supports is technology.

Assistive technologies (ATs) are technologies that have been modified in some way so they can 'assist' individuals with disabilities in performing functions that might otherwise be difficult or impossible to do. They include hardware, software, digital content, apps, and peripherals that assist people with disabilities in accessing computers or other information technologies.[39]

There are numerous types of ATs,[40] and each has a different compensatory function. For example, adapted trackballs, switches, adapted computer mice and joysticks, and alternate keyboards can help students with motor problems utilise technology. Screen magnifiers, screen readers (such as Job Access with Speech (JAWS)), digital talking books, voice-to-text software, voice notes, and dynamic Braille readers help students who are blind or have some form of visual impairment access digital content. Communication apps, or AAC software, speech synthesisers, sign-language resources, and hearing-microphone sets help students unable to use verbal speech to communicate (Watkins et al., 2011; p. 44; Burns, 2012, p. 84; Lynch et al., 2021).

38 Sustainable Development Goal 4 Target 5 aims by 2030 to eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples, and children in vulnerable situations.
39 Definitions of various ATs can be found here.
40 Many other technologies that are not assistive, for example CAI and online learning, may be used with students with certain types of learning disabilities. For a complete list of assistive technologies based on student need, go here.

Ensuring that learning opportunities are accessible to all learners regardless of disability in face-to-face and distance settings is increasingly in the forefront of instructional design. The National Instructional Materials Accessibility Standard (NIMAS) stipulates that all textbooks be available as digital source files—fully marked up in Extensible Mark-up Language (XML) source files based on the Digital Accessible Information System[41] (DAISY) international standard (National Centre on Accessible Educational Materials, 2020).

The DAISY format ensures flexible and navigable reading experiences for people who are blind or print disabled in a number of countries worldwide, such as Sweden, Finland, France, Japan, Canada, Germany, Switzerland, Spain, Australia, New Zealand, Norway, the United Kingdom, the Netherlands, Denmark, and the United States. DAISY books and cognitive tutors provide scaffolds, such as human narration, synchronised audio and text markings, and model tracing to gauge where students have difficulties and where they need interventions. The format was used to aid the evolution of the EPUB format, embedding accessibility features at the very foundation of this e-book format. The digital source file can be transferred to those accessible formats needed by students with disabilities (e.g. a Braille book or digital talking book), and one piece of content then can be displayed in many different ways (The DAISY Consortium, 2021; Burns, 2011, p. 149).

41 The DAISY Consortium is an international association that develops, maintains, and promotes international DAISY Standards. It was formed in May 1996 by talking-book libraries to lead the worldwide transition from analogue to Digital Talking Books.

3.1.5.1 ACCESSIBILITY FEATURES IN NON-ASSISTIVE TECHNOLOGIES

In addition to these specially designed accessibility efforts, hardware (e.g. Chromebooks), standard operating systems (e.g. Windows), office software packages (e.g. Microsoft Office), and e-learning tools (e.g. Articulate360) are increasingly paying attention to accessibility, embedding such features as immersive readers, word prediction, text-to-speech, and speech-to-text tools to help users access, navigate, and comprehend information, and produce content. Interactive whiteboards deliver audio-visual content that can be augmented in size and sound for students in the back of the class or those with visual problems or hearing problems.

Online content is consistently being built to meet Web Content Accessibility Guidelines (WCAG)—which provide a single, shared standard to make web content more accessible to anyone with disabilities (Web Accessibility Initiative, 2021). For example, Canvas, an LMS, is certified WCAG 2.1 and features a built-in accessibility checker for common accessibility errors, such as the use of sufficient colour contrast for text and alternative text for images for individuals who are visually impaired. The checker can be accessed while an educator is building course content. (Other LMSs, such as Moodle, have similar features.) Google's G Suite EDU has designed numerous accessibility features in the Chrome browser as well as in Chromebooks, such as select-to-speak, which allows students to choose which text they want read aloud and to

> Universal design for learning (UDL) is a design technique that focuses on creating the least restrictive environment for access to learning.
>
> To explain UDL, we use the metaphor of entry into a school. A ramp is an example of a universal design technique. Unlike stairs, which make access to the building difficult, or impossible, for individuals in wheelchairs, elderly or frail individuals, or people with mobility impairments, a ramp allows for *universal* access to a building—equally accessible by those with physical impairments and those without (CAST, Inc., 2021). The goal of UDL is to ensure that all learners are purposeful, motivated, resourceful, knowledgeable and goal directed (S. Knapp, personal interview, July 2021).
>
> Educators, including curriculum and assessment designers, and teachers can improve educational outcomes for diverse learners by applying the following principles to the development of goals, instructional methods, classroom materials, and assessments.
>
> *Provide multiple and flexible methods of presentation* to give students with diverse learning styles various ways of acquiring information and knowledge.
>
> *Provide multiple and flexible means of expression* to provide diverse students with alternatives for demonstrating what they have learned.
>
> *Provide multiple and flexible means of engagement* to tap into diverse learners' interests, to challenge them appropriately, and to motivate them to learn (CAST, Inc., 2021).

Box 15: *Universal design for learning* adjust pitch, speech rate, and volume accordingly (Google for Education, 2021). Web sites such as Accessible YouTube, Easy Chirp,[42] and You Describe are accessible social media sites.

3.1.5.2 BENEFITS OF ASSISTIVE TECHNOLOGIES

ATs can also help many students who have learning disabilities. Learning disabilities, unlike physical disabilities, are cognitive in nature and may include dyslexia, dysgraphia, dyscalculia, among others, and related disorders such as attention-deficit/hyperactivity disorder (ADHD), dyspraxia and issues with executive functioning and mental health (National Centre on Learning Disabilities, 2019). While accessible materials and technologies are valuable supports, they may not be enough. AT needs to be embedded within the design of quality instruction and digital materials, and learning activities themselves must be universally designed so that all learners can navigate a website, access content, and participate in online and in-class activities regardless of their ability (see Box 15).

Clearly, technology extends numerous benefits and supports to students with physical disabilities and with learning disabilities. It delivers access to the curriculum and to learning activities, generates data to inform teacher instruction; helps individuals set goals; and enables students to interact and participate with classmates. It lessens learners' dependence on a teacher or teacher assistants to read or write, and it can support learners who struggle with certain physical or cognitive tasks (Centre for Applied Special Technology, 2021).

3.1.5.3 CHALLENGES ASSOCIATED WITH ASSISTIVE TECHNOLOGIES

However, AT creates challenges for education systems, particularly poor ones. It is expensive, particularly in low-resource contexts. To use assistive devices well, they must be part of a whole accessibility approach that looks at design and instruction, yet education systems often make procurement decisions without such considerations. The challenges of AT are further compounded on the supply side. For instance, large technology companies often adopt a 'feature checklist' approach to design (adding, for example, text-to-speech features) versus a task design approach (how students will use these features) that leaves students frustrated because of too many steps to use the features (S. Blackstein-Adler, personal interview, July 2021; National Centre for Learning Disabilities, 2019). Many large technology companies do not collaborate closely enough with

42 As of this writing, this site is still in use but no longer maintained.

manufacturers of Ats. The result is that one AT application will work well in one environment (Google or Microsoft), but not in the other (S. Blackstein-Adler, personal interview, July 2021).

Teachers, too, face challenges using ATs. Many are often unaware and untrained in using accessibility features and ATs, particularly with highly specialised assistive devices (National Centre for Learning Disabilities, 2019; Lynch et al., 2014). And with non-assistive technologies, teachers need professional development and ongoing coaching in how to effectively integrate AT into classroom instruction and how to differentiate and use specially designed learning materials (S. Blackstein-Adler, personal interview, July 2021).

There are other issues, too. A lot of standard software and digital content fall short of UDL principles. Students with disabilities is a population requiring comprehensive and systematic curriculum materials that provide differentiation, but in reality, that is often not the case (National Centre for Learning Disabilities, 2019; S. Blackstein-Adler, personal interview, July 2021). Above all, there is little research on the technologies used to provide education to students with special needs, particularly in the Global South (Lynch et al., 2014). Failure to address these issues, as has been largely the case thus far, threatens to exacerbate the digital divide for learners with disabilities (Tausin and Stannard, 2018).

3.2 TECHNOLOGY FOR DELIVERING LEARNING: ADDITIONAL AREAS FOR RESEARCH

The importance of technology as an educational delivery tool is defined by its presence—and by its absence.

Where appropriate infrastructure and equipment exist, technology can deliver learning to teachers and students. Assistive technologies have made learning and communication easier for many children with mobility, auditory, speech, and visual challenges. Radio has proven that it can provide learning to children in geographically isolated areas and to children learning from home because of Ebola or COVID-19 in some of the poorest places on earth. In refugee camps across Sub-Saharan Africa and the Middle East, students and teachers have access to learning opportunities that might be otherwise unavailable thanks to online and mobile learning initiatives. Distance technologies can compensate for the shortage of teachers and provide high-quality educational materials, such as videos, interactive software, or text-based information to support formal, informal, self-paced, and self-directed learning for students as well as upskilling for those in the workforce (Olson et al., 2011).

However, for significant portions of the planet, it is the absence of technology that is most profound—and most harmful. As the world pivoted to remote learning during the COVID-19 pandemic, students fortunate enough to have a computer and internet at home participated in learning via high-tech delivery systems, such as online learning and video-based live synchronous classes. Those in far more resource-deprived areas participated in continuous learning via low-tech delivery mechanisms, such as radio, text messages, automated voice message (AVM), and interactive voice response (IVR) (Grant and Morrell, 2021). But hundreds of millions of children across the globe, particularly in Sub-Saharan Africa, without access to electricity, to television, to the internet, and to any kind of technology were largely excluded from any kind of education at all (UNESCO, 2020c).

The absence of a technology infrastructure, particularly mobile and fixed broadband infrastructure, and the tiered system of technology access described in the above paragraph expose the distance education caste system to which the world's students are consigned: The wealthiest students get online learning; poorer students get radio or TV; poorer ones still settle for digital or analogue substitutes; and the poorest students get nothing. This inequitable access to technology further exacerbates existing educational disparities.

However, on its own, access to connectivity and devices does not guarantee access to engaging educational experiences or a quality education (Office of Education Technology, 2017, p. 24). This raises another issue that afflicts technologies used for educational delivery. For instance, no other distance technology medium combines so many channels of learning—text, audio, video, multimedia—as online learning. No other distance education medium can approximate the classroom experience and connect learners in real-time to their teacher, to each other, and to expertise across the globe. Yet questions persist about the quality of online learning, and the research about its benefits are still more suggestive than conclusive.

As with Section 2, this section concludes with recommended research questions that focus on issues of equity and quality in terms of technology to deliver learning. These suggested research questions are outlined in Table 6.

Category	Suggested Research Questions
Equity	• Which distance technologies can best provide inclusive and equitable access for the world's most marginalised learners? • How can we evaluate the conceptualisation, design, testing, and impact of appropriate technology within different environmental conditions, such as gender, age, and location (urban, peri-urban and rural, public/private schools, and curriculum area), to meet the needs of the full range and diversity of learners with disabilities in LMICs? (Lynch et al., 2021, p.14) • How can technology ensure inclusive and equitable quality learning experiences for learners with disabilities? (Lynch et al., 2021)
Quality	• What empirical benchmarks of comparison best reflect the nature of technologies being evaluated, their target population, and the outcome measures being used? (Hill et al., 2008) • Is online learning as effective as face-to-face instruction for all students and if so, under what conditions? • What factors influence success in online learning among culturally, professionally, and geographically diverse populations, with different audiences, and in different models of online learning (e.g. online courses of short duration)? (Burns, 2013b)

Table 6: *Suggested questions for additional research (Section 3)*

SECTION 4: TECHNOLOGY TO SUPPORT LEARNING

The previous two sections discussed technology as a tool for learning and technology as a tool to deliver learning. This section discusses technology's role as a support for learning. It discusses both current and emerging resources and technologies that may potentially support quality and equitable educational delivery and learning to students and teachers.

4.1 TECHNOLOGY SUPPORTS FOR TEACHING AND LEARNING AND EDUCATIONAL DELIVERY: STRIVING FOR EQUITY AND QUALITY

Much (digital) ink has been spilled ruing technology's failure to 'transform' education, but such accusations are misleading. Technology has become indispensable as a support for learning and as such has indeed transformed many of the foundational elements and supports associated with teaching and learning.

Since its introduction into the education system, technology has provided major logistical supports for the teaching and learning process: in locating and assigning resources required to accomplish an assignment; producing affordable, high-quality educational materials at scale; ensuring access to multimodal content; creating class schedules and teaching timetables; providing targeted completion times and rates of progress; generating highly specialised tests that measure unique constructs; organising and collating information about students; furnishing student data profiles (among other tasks); and making educational processes more efficient, less expensive and less labour-intensive. Indeed, research suggests that technology used to support instruction has a marginally but significantly higher average effect size versus technology for direct instruction (Tamim et al., 2011, p. 17), although the types of supports are not clearly delineated.

While technology's benefits in terms of supporting learning cannot always be quantified, they are real and have enormous value. Technology has functioned as a tool of replacement, access, dissemination, enhancement, and automation. For example, at the most basic *replacement* level, because of unlimited storage capacity, web pages and digital readers (e.g. Kindles and tablets) have replaced books and made reading more accessible to students. Increasingly fast processing speeds mean that Student Information Systems (SIS) generate more data more quickly than a paper report card, thus, for example, spotlighting student performance on learning outcomes and allowing for shorter feedback loops. Electronic databases have replaced file cabinets so that information can be instantly searched and found using multiple search terms. We can—and should—argue about the quality, the greater significance, the motivations, and the ethics driving these developments. We cannot deny, however, that technology has automated, made more efficient, expanded, and changed existing educational practices (Weston and Brooks, 2008).

This section examines emerging technology-based supports to make learning more accessible, equitable, and qualitatively better for learners everywhere. These supports for learning are often designed by those other than the teacher or student (with the exception of OER). Most of these supports are not new. However, technological developments, improved computing power, and increased access to technology make these supports potentially impactful as they are harnessed to address vexing issues of quality and equity. But even as they aim to redress these issues, many of these supports also raise questions about the values and priorities of education systems and the trade-offs between the benefits of innovation and the unintended consequences that undermine the very equity and quality that technology seeks to foster.

4.1.1 DIGITAL CONTENT

To teach and learn through and with technology, teachers and students need access to content and resources. Development of content is one of the largest cost drivers in technology-based education—particularly in self-paced and asynchronous online courses, where high-quality interactive content essentially constitutes the entirety of learning. Across the globe, ministries of education and schools have handled content development differently—from purchasing educational materials from international media companies to developing their own educational content in partnership with universities, local media, and/or digital design companies (Burns, 2011).

The cost of content, the monetisation and commercialisation of previously free content and platforms, and the fact that educational technology, globally, as noted in Box 2, is 'big business,' potentially threatens access to quality learning opportunities for those with limited financial means, particularly learners in the Global South. The Open Education movement has emerged as a counterweight to these forces. Its defining ethos is that access to knowledge should be free, open, and offer high-quality learning to learners everywhere.

Open education is part of a whole ecosystem of 'open solutions,' which includes concepts of open access, open data, open assessments, open pedagogy, open software, and crowdsourcing (UNESCO, n.d.). It includes research reports (open research); computer code and programming languages (e.g. Python, R, C++, Java, JavaScript, and other languages found on sites like GitHub); e-learning development tools, such as H5P or Twine; platforms (e.g. LMS, Moodle; the web browser Firefox, or

Open licenses are conditions applied to an original work (i.e. any creation, such as a video, text, or piece of software) that grant permission for anyone to make use of that work as long as they follow the conditions of the license. The copyright owners—usually the creators of the work—can choose to openly license their work if they want others to be able to use it freely, build on it, customise it, or improve it. Open licenses thus give permission to anyone to use the work at no cost, and they generally allow anyone to modify the work with no or minimal restriction (Year of Open, n.d.). There are numerous open licenses that follow these principles, such as Creative Commons licenses. A list of open-source licenses can be found at the Open-Source Initiative.

OpenCourseWare (OCW) is open, modular, and flexible electronic course content, typically developed by universities for their students and freely available through the World Wide Web. Materials in OCW collections are not simply freely available—their re-use and adaptation are also encouraged. Many of these resources are licensed under a Creative Commons license allowing for distribution, remix, and re-use of materials (C. Newton, personal interview, May 2021).

Open-source software (OSS) is software whose code is freely available so that other programmers can modify and customise it. It is identified by the type of license under which it is released. These licenses include the Apache 2.0 license, the Microsoft Public License, and the GNU344 General Public License. Essentially, open-source licensing, like all open content and courseware, encourages a shared community approach to the development, extension, and patching of OSS. A common misconception is that all OSS (indeed all open content) is *free*. While this is usually true, it is not always the case. Hence the designation FLOSS—Free/Libre Open-Source Software. Similarly, there is often a misconception that all free content and software is open source. This, too, is not true. For example, Edmodo is a free educational platform, but its source code is not available, thus it is not open. Many free education platforms may in fact have rights over the user content that is created in these sites (Year of Open, n.d.; Burns, 2011: 233-234).

Copyleft, a sub-source of OSS, grants users the right to freely distribute and modify intellectual property with the requirement that the same rights be preserved in derivative works created from the original property (Wikipedia, n.d.).

Open pedagogy is the practice of engaging with students as creators of information rather than simply consumers of it. It is a form of experiential learning in which students demonstrate understanding through the act of creation (C. Casserly, personal interview, May, 2021).

Box 16: *Open education terms*

the operating system Linux[43]); or open systems, such as Open Student Information Systems and Open Artificial Intelligence (OpenAI[44]); and open content, such as free and open textbooks.

The open education movement is vast, and space limitations prevent a full examination of it in this think piece. Nonetheless, Box 16 points out a few additional elements of the open education ecosystem and this section discusses what may be the most important element of the open education movement for teachers and students—open education resources (OERs).

[43] While these platforms may be open source, that does not mean the content they host is necessarily open source.
[44] Open AI is a part-commercial, part not-for-profit laboratory.

4.1.1.1 OPEN EDUCATIONAL RESOURCES

OERs are teaching, learning, and research materials in any medium—digital or analogue—that reside in the public domain or have been released under an open license that permits no-cost access, use, resharing, adaptation, and redistribution by anyone with no or limited restrictions (UNESCO, n.d.; Centre for Research and Innovation in Education, 2007).

Historically, open education initiatives have tended to be more common in the higher education space —driven mainly by the high cost of university textbooks, particularly in the United States and Canada. Developers such as OpenStax and initiatives such as ALX have long provided low-cost textbooks and helped teachers create and adopt OER to supplement deeply discounted publisher textbooks, respectively, thus saving students millions of dollars (Pelletier et al., 2021). The Sydney (Australia) Open Library hosts open-access academic textbooks published by Sydney University Press, covering topics across the humanities and social sciences. Boston University's Building Blocks (BULB) allows university instructors to create open and iterative educational resources within WordPress using the Gutenberg editor for their online and blended courses. These can be stand-alone pages or as an ordered sequence of multiple lesson pages (Boston University, 2021).

However, OER initiatives across the globe are expanding, too, with regional and continental initiatives such as BCcampus and OER Africa, respectively (BC campus, 2021; OER Africa, 2021). Since 2005, Teacher Education in Sub-Saharan Africa (TESSA) has produced a range of context-specific open materials in several languages with educators across Sub-Saharan Africa and India. The Enseña Chile Foundation's open and free platform makes learning resources available to students and teachers in the country via different channels such as radio and support via WhatsApp and podcasts (La Tercera.com, 2020). Efforts by organisations such as the Wikimedia Foundation, The William and Flora Hewlett Foundation, Commonwealth of Learning, Virtual University of Small States of the Commonwealth, Siyavula, the Raspberry Pi Foundation, the South Africa Institute of Distance Education, KnowledgeforAll (K4A), and UNESCO, particularly via its Recommendations on OER, have helped to extend open learning resources to many parts of the Global South.

Many governments, too, have come to embrace and invest in OER—and not just at the university level (Griffiths et al., 2020). Poland in 2014 adopted openly licensed publicly funded textbooks (both digital and print-based) for the entire national education system. Fiji adopted a national OER policy, OER repository, and open licensing for publicly funded educational materials and research. Brazil has set open licensing requirements for digital resources that come with textbooks the government purchases for the nation's schools, and the Ministry of Education is developing an OER repository. In South Africa, Siyavula and the Department of Basic Education (DBE) collaborate to print and distribute copies of open math and science textbooks, workbooks, and teacher guides to government schools across the country (The William and Flora Hewlett Foundation, 2019b, p. 4). The European Network for Catalysing Open Resources in Education (ENCORE+) promotes the adoption of OER in Europe through the development of a European OER ecosystem, including a sustainable collaboration model, an OER quality framework, and OER strategy guidelines for higher education and business (Pelletier et al., 2021, p. 26).

OER, and the whole open education movement it has spawned, has yielded numerous benefits. First, OER is cost-effective. Because open licenses allow for remix and redistribution, content and materials developers can repurpose, translate, and localise these materials without paying licensing fees, thus making educational content more affordable for low-resource education systems.

Second, OER often addresses the educational needs and contributions of under-represented communities and may empower traditionally overlooked communities to create their own educational content, based on their own experiences and local cultures, to promote more culturally responsive and inclusive education.[45] Several cases illustrate this point. The Wikimedia Foundation hosts educational content created or repurposed for linguistic communities (e.g. Basque speakers) who are often not served by commercial education content developers. In Chad, Kenya, Lebanon, and Niger, the Carey Institute for Global Good has taught refuge teachers how to create OERs in Arabic, English, and French as part of its Refugee Academy Network (Carey Institute for Global Good, 2021). This involves creation of professional development courses, toolkits, communities of practice, micro-credentials, and learning analytics. The Canadian initiative, *Learning to Code, Coding to Learn*, jointly run by Bridges, Canada, and the Inclusive Design Research Centre at the Ontario College of Art and Design, uses an open-source coding platform, Weavly, to support students with complex learning needs learn how to code (S. Blackstein-Adler, personal interview, July, 2021).

Third, through OER, MOOCs, Open Textbooks, zero cost university degrees ('Z degrees'), Open Badge Microcredentials,[46] and Open Pedagogy (See Box 16), the whole open education movement has done much to promote attainment of SDG4, particularly in terms of access to lifelong learning opportunities. Students whose formal education is disrupted for any reason can use OER and OpenCourseWare (in combination with other digital content such as YouTube videos) to continue

[45] See, for example, the Images of Empowerment collection.
46 Open Badge micro-credentials were created in 2011 by the Mozilla Foundation, with financial support from the MacArthur Foundation. Open badges are a visual certificate of accomplishment for informal and formal, continuous, and typically 'short' or 'micro' learning (e.g. completion of short online course or participation in an online seminar). They contain metadata—data that provides information about other data—such as the issuers of the badge and the competencies attained and are therefore verifiable. For a complete list of badging options (commercial and open source), visit here and here. Additional information about badges themselves and the metadata associated with open badges can be found here and here.

learning and even transcend the limits of their local education system to pursue advanced studies in areas that interest them but that might otherwise be unavailable (C. Newton, personal interview, May 2021).

These expanded learning opportunities resonate particularly in the Global South, provided learners have internet or cellular network access. Seventy percent of the two million unique monthly visitors to the Massachusetts Institute of Technology's (MIT) OpenCourseware (OCW), which includes material from 2,500 MIT courses, come from outside North America, with 20% of visits alone coming from India and Pakistan (C. Newton, personal interview, May 2021). For locations with unreliable or limited internet access, certain OCW programmes, such as MIT's, have established 'mirror drive' programmes to deliver digital content onto a hard drive so students can access courses via their local network (C. Newton, personal interview, May 2021).

Fourth, regardless of where students live, the open education movement represents a commitment to making continued education more affordable for students. In the US state of North Dakota, a state audit of the North Dakota University System revealed that a US$107,250 investment in 'open education resources training' to bring OER to universities yielded between US$1.1 and 2.4 million in savings for students (Gallion, 2018). In Rhode Island and California, similar statewide initiatives to make higher education free for low-income students (Z degrees) have adopted open textbook initiatives as part of these efforts (State of Rhode Island Office of Innovation, n.d.).

Fifth, there is evidence from multi-country programmes such as TESSA and large-scale studies of the use of OER in universities in the United States, that suggests OER yields 'similar or better' student learning outcomes than traditional textbooks and that it improves end-of-course grades and course completions (Gallion, 2018, p. 14; The William and Flora Hewlett Foundation, 2019b; Griffiths et al., 2020; Colvard et al., 2018).

Nonetheless, OER faces real hurdles in terms of large-scale adoption. There is often a lack of awareness about OER, particularly in North America, as well as concerns about the accessibility of OER for learners with disabilities. Different regions of the globe approach OER differently, which results in differences across countries in terms of policy, adoption, and implementation (The William and Flora Hewlett Foundation, 2019a). Despite regional initiatives such as OER Africa and OER Asia, a lot of OER is developed in the Global North and thus may be inappropriate linguistically and in terms of alignment to local curricula and syllabi (Orwenjo and Kanan, 2018). Many of the weaknesses of OER are intrinsic to the very notion of OER itself. Because they can be developed by anyone and because education systems may not have standards, rubrics, or checklists for assessing quality, the doubts about the quality of OER persist. These questions of quality may be exacerbated by the complexity of open software itself. For example, as an e-learning developer, the author can attest to the steep learning curve and time-consuming nature of designing digital content with open tools for open platforms which can, in turn, affect the quality of the digital products designed. Because the OER field continues to evolve, there are issues with existing research, including questions about rigour, its over-representation of higher education settings, and its dominance by researchers in the Global North (The William and Flora Hewlett Foundation, 2019a; C. Casserly, personal interview, May, 2021; A. DeBarger, personal interview, July, 2021).

Finally, OER developers do not have the ubiquitous marketing strategies of commercial software developers and thus often do not have the ear of ministers of education (C. Casserly, personal interview, May, 2021). However, this may change with international initiatives such as the Ljubljana OER Action Plan that emerged from the Second World OER Congress (United Nations Educational, Scientific and Cultural Organization, 2017). The Action Plan advocates mainstreaming OER to help all Member States create inclusive knowledge societies and achieve the 2030 Agenda for Sustainable Development. This Action Plan is aligned with larger UNESCO initiatives around OER to meet SDGs 4, 5, 10 and 17[47] (United Nations Educational, Scientific and Cultural Organization, 2019).

The open content movement, specifically OSS frameworks for machine learning, and open-source tools have been an enormous benefit for both data collection and the development of artificial intelligence (AI) (Engler, 2021). In turn, both data and AI have proved to be powerful supports for teaching and learning, as the following pages discuss.

4.1.2 BIG DATA (LEARNING ANALYTICS)

Walk into a classroom and watch a teacher as she walks around the room. Periodically she'll stop and talk to students or sit down and answer questions from a small group of students. She may walk up to a desk and gently remove a phone from a student's hand, redirecting him/her to the task at hand. She may occasionally stop and speak to the whole class to clarify a question or offer general guidance based on what she's observed.

This teacher is using data. Teachers have always used data as part of diagnostic, formative, and summative assessments to redirect learning, provide students with guidance and feedback, modify instruction, clarify a particular point, or make a determination about student learning. In addition to

[47] SDG 4 (Quality education), SDG 5 (Gender equality), SDG 10 (Reduced inequalities within and across countries), and SDG 17 (Partnerships for the goals) (United Nations Educational, Scientific and Cultural Organization, 2019).

tests, teachers do this by listening, observing, asking questions, walking around the classroom, and listening to students.

The use of data in education is not new. What *is* new (relatively) is digital data, particularly in situations where teachers and students are separated by distance (such as, online learning) and with computer programmes, such as CAI and intelligent tutoring systems (ITS), where the computer, rather than the teacher, directly instructs students.

Data collection and analysis powered and automated by technology have created numerous educational benefits and innovations in everything from building schools and allocating teachers to instruction and assessment. The Kenya School Mapping project, for example, used geographic information systems (GIS) to collect data on the location and physical condition of facilities, enrolment, and the number of teachers for educational planners. Spatial analyses with GIS have proved to be invaluable for reallocating teachers based on actual need in countries such as Indonesia, Malawi, The Gambia, and Philippines (Asim et al., 2017).

What has particularly excited education policymakers and planners is the capture and analysis of student data to improve student learning. Real-time individualised data can provide insights into how individual students learn and what kind of tutoring they need (Maull et al., 2014; van Dijck and Poell, 2018, p. 42). Back-end data analytics in online courses can alert the teacher to students who are falling behind or are at risk of dropping out of an online course. Continuous monitoring and measuring of student performance, particularly via formative assessments, can help teachers better focus efforts on learning outcomes for subjects with which students are having difficulty or use more targeted and effective instructional strategies, such as mastery learning, teaching at the right level, small-group tutoring, and individualised and personalised instruction (Gustafsson-Wright et al., 2021).

All of this student information is packaged as ‘learning analytics.’ This involves data mining, which involves capturing student data (preferably large quantities of it) and analysing it in real time for benchmarking and reporting. This reporting often occurs via data dashboards that visually display ‘undesirable’ learner behaviours (e.g. failing to turn in an assignment or failing a quiz), thus allowing the computer programme or online course teacher to provide just-in-time intervention, support, and adaptation of learning; suggest supplemental learning resources; or reach out to a particular student. But there’s more. Using historical data, machine learning and algorithms, these data can be used to make inferences about—or predict— the learner’s future performance, hence the term ‘predictive analytics’ (Tempelaar et al., 2015; van Djick and Poell, 2018; Holon IQ, 2021).

Big data (at the aggregate vs. the individual level) combined with predictive analytics also help software developers enhance and adapt their educational products and provide the 'fuel' to develop and improve educational processes and software applications, such as AI and the personalised learning programmes discussed in Section 2 (Holon IQ, 2021; van Djick and Poell, 2018; Macleod, 2021). Across the education system *writ large,* data dashboards can help educators track learner performance across time as well as monitor groups of students to identify shifts in equity, opportunity, and achievement gaps (Office of Educational Technology, 2017, p. 263).

These and other educational technology-related activities have had salutary educational effects, as the following discussions on AI and personalised learning will demonstrate. They are also worrisome. The constant monitoring; datafication of learning; and data-intensive systems that quantify, analyse, and make predictions about the cognitive, affective, and social behaviours of students are often unregulated and unchecked (van Dijck and Poell, 2018; Privacy International, 2020). The urge to hoover up all kinds of data on technology users raises serious ethical, safety, and policy concerns about the commodification of data, privacy, and security; data protection protocols; data-sharing agreements; potential misuse of data; and the need for more ethical technical and policy guidance to regulate data collection, especially within education settings (Macleod, 2018; Privacy International, 2020; van Dijck and Poell, 2018).

4.1.2.1 DATA SECURITY AND PRIVACY

If the product is free, you are the product.[48]

The above observation may best encapsulate the relationship between technology companies and their users—that is, students and teachers (Done, 2010). Large for-profit technology companies, social media platforms, app developers, and educational service providers, such MOOCs, collect and store basic data such as users' names, addresses, and contact information. They also have easy access to the contents of users' emails, text messages, videos, call logs, photos, videos, contact lists, and calendars. These data are often stored on the cloud—online data centres plus the software and databases that run on those servers, dominated by technology titans like Amazon, Microsoft, Google, and Alibaba.

The business model of many technology companies and providers is often to repurpose, sell, analyse, and share insights on users for targeted advertising. This commodification and monetisation

[48] The original source of this quote is unclear. To dig deep into its provenance, follow this link: https://tinyurl.com/4r767d8h.

of data are profitable for companies, but their data subjects—students—derive no financial benefit from these transactions. Rather, students are subjected to monitoring, A/B testing, targeted advertising, marketing, and manipulation—all without their consent (Privacy International, 2020; Nicas, 2021). There are few limits on the ability of technology companies and educational technology providers to refrain from such activities. The lack of universally recognised data protection standards, consumer protection laws, and privacy regulations; the geographic transcendence of the internet; the misalignment between national or market-sector privacy laws and global data flows; and the enthusiasm of some governments to surveil their own students and teachers for political purposes makes consistent, coherent policy on student and teacher privacy extraordinarily challenging (Privacy International, 2020; Global System for Mobile Communications, 2016). Other inconsistencies abound. For example, certain types of data (say, a user's location) are subject to privacy rules when processed by a mobile operator but not when processed by an internet content provider (Global System for Mobile Communications, 2016).

While wealthy countries often have strong data protection standards, Privacy International (2018) cautions that the risks to student and teacher privacy and security are greatest in Global South countries where data protection standards may be weak or unenforceable and where many governments may welcome control and surveillance over their populations. Data protection standards are problematic too in countries that suffer from a lack of 'transparency in decision-making processes, limited rule of law, and (where) the responsibilities of the private sector are blurred' (Privacy International, 2018, p. 5). Increased amounts of time on social media, participation in online learning (especially as a result of COVID-19) and accessing cloud-based educational applications means that students everywhere have become 'unwitting participants in market and social experiments' (van Dijck and Poell, 2018).

Personal information includes, but is not limited to, any data or information that is collected:

- Directly from a user (e.g. entered by the user via an application's user interface and which may include name, address, etc.)
- Indirectly about a user (e.g. mobile phone number, email address, name, gender, birth data, location data, IP address)
- From a device about user behaviour (e.g. location data, website visits)
- From a device generated by the user (e.g. web cookies, messages, user-generated images, etc.) (Global System for Mobile Communications, 2016).

Certain categories of personal data are considered sensitive since dissemination of such information could pose a significant risk to those individuals. These data include a user's racial or ethnic origins, religious affiliation, gender identification, sexual orientation, mental health status, or political beliefs. Sensitive data require higher safeguards, including limitations on the permitted grounds for processing it (Privacy International, 2018, p. 26; European Union, 2021).

Even if a user doesn't actively share sensitive information, it is easy enough for technology companies to access it. Marketers assign an ID to a device and then monitor a user's web and in-app behaviour across different platforms to generate composite profiles of demographic information, purchasing habits, and life events. Companies routinely sell this information, and may turn it over, if ordered by governments (Newman, 2021; Nicas, 2021).

Protecting personal data is increasingly a concern for those in LMICs. For example, over a third of adults in Brazil and Guatemala report real concerns about the security of their personal information (GSMA, 2020).

Box 17: *What is personal information?*

Data confidentiality and integrity are particularly important to vulnerable and marginalised populations, such as refugees, migrants, internally displaced populations (who may not be protected by national laws on data protection and security), and religious, sexual, and/or ethnic minorities (Macleod, 2021; Privacy International, 2020).

4.1.2.2 ENFORCING DATA PRIVACY AND PROTECTION IN EDUCATION

The solutions to rein in data harvesting rest with governments and technology companies (mainly) plus educators and their students. Box 18 provides three examples of data privacy and protection laws for students in the United States. In addition, the European Union's General Data Protection Regulation (GDPR) is a major step toward more universal privacy protections. It explicitly outlines consent and rights of individuals and puts the onus on data companies to show how they are complying with laws and shaping global data privacy and protection norms.

However, countries need to develop their own approach to regulating the use of personal data in line with local priorities, needs, and capacities (Global System for Mobile Communications, 2016). Governments could adopt this framework and ensure that rules for data security and privacy are applied consistently to all players in the internet ecosystem while also implementing data privacy laws that support innovation and protect students. Even without a supra-national framework, governments can compel technology companies to make their policies on how they share user data and track those users across services for targeted advertising more transparent (Newman, 2021). Regulations can impel companies to enforce strong laws about true consent (and who, reasonably, can grant consent); rights to privacy and confidentiality; how data,

> The Family Education Rights and Privacy Act (FERPA) affords parents the rights to (1) access their children's education records, (2) seek to have the records amended, (3) exercise some control over the disclosure of personally identifiable information from the education records. When a student turns 18, or enters a postsecondary institution at any age, the rights under FERPA transfer from the parents to the student.
>
> The Individuals with Disabilities in Education Act (IDEA) ensures that all students with a disability are provided with free appropriate public education tailored to their individual needs. In addition, IDEA contains confidentiality provisions that apply to personally identifiable information (PII) relating to children with disabilities ages 3 through 21 who are referred to, or receive services under, IDEA Part B. PII includes the names of the child, the parent, or other family members; the child's address; a personal identifier, such as the child's social security number or student number; and a list of personal characteristics or other information that would make it possible to identify the child with reasonable certainty.
>
> The Children's Online Privacy Protection Act (COPPA) imposes requirements on operators of websites or online services directed to children under 13 years of age and on operators of other websites or online services that collect personal information online from a child under 13 years of age. Under certain circumstances, schools may consent to data collection on students on behalf of parents but only when such data are used for school-authorised educational purposes and not for commercial purposes.

Box 18: *Examples of national data privacy laws for children from the United States* devices and technology infrastructure are protected at every level of data processing (generation, collection, retention, and sharing); how user confidentiality is maintained; how reporting and investigating breaches should occur, including informing the relevant supervisory authority and affected data subjects; and how companies will be held to account when they fail to comply with such obligations (Privacy International, 2018; 12, 72–74; European Union, 2021).

International organisations can advocate that data protection measures be implemented for marginalised and vulnerable populations. Many international researchers follow research protocols, such as those outlined by institutional review boards (IRB), but sometimes in the rush to publish, corners get cut. Governments and donors should be sure to emphasise that every educational organisation and individual working on their behalf in the Global South '(gain) consent for the collection and use of such data from the selected individuals; formally (commit) to the secure protection, storage, and transmission of data; and (systematically anonymise) all personal identifiers that could compromise the safety of individuals (Macleod, 2021, p. 49).

Technology companies have an equally important role to play. They can apply robust privacy and data protection to their products, services, and systems. This includes settings that protect *privacy by default*, that is, without any manual input from the user (Privacy International, 2020). Apple claims that its new iOS 14.5 makes privacy the default option.[49] In other words, if iOS users want to be tracked by certain apps and sites, they will need to *opt in* to being tracked by third-party apps rather than handing over their data by default (Newman, 2021).

Technology companies can also ensure *privacy by design*, that is, honouring users' desires for greater privacy, prioritising the needs and concerns of vulnerable groups most in need of protection from data surveillance rather than developing technical workarounds to override those needs and desires (Nakashima, 2018). And they can adopt straightforward, versus opaque, privacy rules and rigorous, transparent protocols that ensure any necessary functional data that are collected eliminate identifying information.

Education systems can mandate openness, transparency, user choice, and control. They can promote the use of browsers with strong privacy controls, search engines that don't track users, greater use of open content and platforms that are not proprietary and profit driven, and the use of end-to-end encrypted communication tools so that only the account owner or the sender and receiver of a message can see the contents. Principals, teachers, and students should have the means and tools to exercise their right to privacy and protect themselves and their data from

[49] There is discussion about whether this is completely true or not: https://tinyurl.com/ccyvch6

abuse.[50] Part of education in a digital age should involve helping students understand data security, how to block cookies from third-party sites, and set their own privacy controls.

Finally, all countries, non-governmental organisations, donors, and education actors can endorse, support, and implement the *Principles on Identification for Sustainable Development*. These principles, to which a variety of bilateral and multilateral aid organisations and UN agencies are signatories, establish the right to a digital identity, ensure data protection and privacy, and provide a secure digital identity. These identification systems, according to the principles, are inclusive, trusted, and accountable, and they are used to enhance people's lives and achieve the Sustainable Development Goals (SDGs) (World Bank Group, 2021b).

For more information on security issues, see Box 19.

[50] Fair Play for Kids and InBloom are two organisations that work to prevent technology companies from collecting data on students. Their sites contain examples of letters and tools parents and communities can use to prevent student data collection by technology companies.

The increased datafication of education and the fact that 'schooling' has increasingly moved online has profound security consequences for education systems across the globe. Increased accumulation of data collection through education management information systems (EMIS); national assessment platforms and online grading systems; student information systems (SIS); Ministry of Education and school websites and social media sites; learning management systems (LMS); and online classrooms mean that increasingly large amounts of data are stored online. This puts schools across the globe at risk for system-wide attacks, such ransomware attacks. (Ransomware is a form of a type of malware that blocks access to an organisation's own data unless it pays a ransom.) It also exposes students and teachers to the risk of personal security breaches and identity theft (Morning Consult, 2021).

Education systems are particularly soft targets. Understaffed IT departments, lack of money to hire network security staff, lack of understanding by users about strong passwords, and open systems that don't limit log-in attempts and that use open remote ports place education systems under increase risks for cyber-attacks (Morning Consult, 2021). Spyware can lurk in 'Trojanised' apps or video game (The Economist, 2021a, p. 44). In 2021, the Broward County school system (Florida, US) was attacked with a demand for $40 million in the crypto-currency, Bitcoin (Coble, 2021). Few education systems are equipped to meet this challenge. The data security firm BlueVoyant analysed 2,702 universities across 43 countries, revealing that ransomware attacks against universities, like that in Florida, increased by 100% between 2019 and 2020, with the average cost of a ransomware attack totalling US$447,000 (BlueVoyant, 2021).

Education systems can begin to address these vulnerabilities. They can adopt 'zero trust' security models—essentially a 'guilty until proven innocent' approach that assumes every connection is a threat. They can hire more network security staff, keep paper backups under lock and key so they do not have to pay to recover their own data in the case of ransomware attacks, invest in strong network security teams, implement multi-step software, set up password managers, and adopt filtering software (BlueVoyant, 2021). As with data privacy, consultation with users, the private sector, and civil society is key to ensuring these are as useful as possible (Privacy International, 2018). Above all, education systems must educate their users—principals, teachers, students, and parents—about basic threats to security, such as phishing, spoofing, cyber-attacks and ransomware—and basic internet safety safeguards, such as requiring all who access an education system's network and platforms to use strong passwords and password managers. Education systems can set up a reporting line where victims can easily report attacks (BlueVoyant, 2021).

An important element of overall security involves personal safety among users. Internet users in LMICs have concerns about information security, contact from strangers, and seeing harmful content. Many of these concerns fall along gender lines. For example, 30% and 36% of women surveyed in the Dominican Republic and Guatemala, respectively, reported concern about their or their family's exposure to harmful content (e.g. violent or sexual content); 20% of Chinese women and 37% of Guatemalan women reported concern about being contacted by strangers online (e.g. sexual harassment or unwanted contact) (GSMA, 2020). These concerns are not unfounded. During COVID-19-related lockdowns, across the globe, the online sexual exploitation of children—many of whom were spending more time online, often without supervision—increased (U.S. Department of State, 2021). Governments can also ensure a safe and secure online experience to all users by developing appropriate legal and policy frameworks that protect and safeguard digital infrastructure and data from cyber threats; recognise digital harassment; educate digital users about safe online behaviours; ensure that digital citizenship, gender sensitivity training, and information literacy are part of school curricula; and make it easy to report online abuse (Privacy International, 2018). They can adopt strong acceptable use policies (AUPs) that clearly define appropriate and inappropriate uses of technology and consequences for violating AUPs. They can harness the internet and social media to raise awareness about risks of online grooming and exploitation of children and adolescents.

Box 19: *Ensuring digital security and safety*

4.1.3 ARTIFICIAL INTELLIGENCE

Every time an SMS client predicts your text or a word processor changes your spelling and grammar or a social media site suggests a story of interest, it is an example of artificial intelligence (AI) in action. Artificial intelligence in education (AIED) is increasingly used to drive access to and quality of education, particularly for underserved groups—developments that could potentially accelerate the attainment of SDG4. However, like big data, which fuels much of the engine of AI, rapid technological developments in AI far outpace debates, policies, and regulatory frameworks governing AI in education (Miao et al., 2021, p. 3).

AI is not one computational approach but a multitude of approaches. Classical—or rules-based AI—uses rules of conditional logic (e.g. *if…then* statements) and has been used for decades to power educational applications (Pelletier, 2021, p. 7). The real power of AI rests with today's evolving and more powerful AI—machine-learning, artificial neural networks (among other computational approaches)—which analyse large amounts of data to build models to predict future values, artificial neural networks, deep learning, etc. (Miao et al., 2021).

AI is increasingly prevalent in education, particularly in higher education, and primarily in wealthier contexts (Box 20 outlines a few examples of how AI is used in education). Universities in the United States, Australia, New Zealand, Germany, France, and the Netherlands are using AI to refine and deepen teaching and learning. Some examples include using machine learning

Chatbots: A chatbot is a software application used to conduct online chat conversation via text or text-to-speech. Using human dialogue analysis and human behaviour recognition, chatbots are able to answer simple questions, assist in basic problem solving, and provide learners with just-in-time rudimentary supports. As chatbots continue to use AI techniques, which make it possible to study natural language and voice patterns, they should be able to handle more complex requests and offer more dialogue-based support and assistance (Holon IQ, 2021).

Curriculum on demand: These are digital resources, such as text, media, learning activities, assessments, and lesson plans, that are curated and generated for students. They are linked to national standards and student learning outcomes. They can be personalised as playlists based on real-time data analysis on student learning student performance. *Learning Passport Zimbabwe*, developed by Microsoft and UNICEF and launched in March 2021, is one example (Rwezuva, Mutsiwegota, Michels, Feki and Eun, 2021).

Digital teaching assistant: Computer-based 'teaching assistants' can be avatars or interactive voice response (IVR) systems (think Alexa or Siri). They are created through the integration of data on student questions and natural language processing. Digital teaching assistants are increasingly found in online courses. They can answer student questions, take attendance, and perform many basic teaching tasks to free up the teacher for more complex tasks (Holon IQ, 2021; Goel, 2016).

Box 20: *Examples of AI in education* techniques to better understand self-regulated learning; creating personalised scaffolds to encourage students' metacognitive skills; supporting reflective teaching practices through lecture transcript analysis; and helping university students develop AI competencies (Pelletier et al., 2021).

But, because it underpins the design of much of the technology that education systems use, AI is also increasingly common in education systems across the Global South[51]—from pre-primary to tertiary and in both formal and informal education. As one example, many of the personalised learning programmes, mobile apps and online courses, discussed in Sections 2 and 3, used to provide education to refugees or students in schools with no teachers or out-of-school youth are driven by artificial intelligence.

Here are just *some* of the ways that AI supports administrative, instructional, and assessment functions of education—EMIS;[52] exam proctoring; automated grading, assessment, and reporting functions; adaptive learning programmes; student information systems; 3D printing; robotics; writing, computational and design support offered by Microsoft Office software; test preparation; formative feedback in online courses; library services; admissions; eye tracking, and facial recognition software measuring engagement and assessing where students need support; game-based learning techniques to measure complex cognitive and SEL skills; stepwise ITS (see Box 21); virtual reality tools; natural language processing platforms where students practise a non-native language with an avatar; disability support; converting still images to video; mobile apps; and data dashboards to drive data-based decision-making (Zheng et al., 2021; Pelletier et al., 2021; Holon IQ, 2021; de Boulay, 2016; Verbert et al., 2013).

51 For a more complete look at AI projects in the Global South, visit Knowledge for All's Global South Artificial Intelligence Directory.
52 An Educational Management Information System (EMIS) is a computer-based 'system for the collection, integration, processing, maintenance and dissemination of data and information to support decision-making, policy-analysis and formulation, planning, monitoring and management at all levels of an education system' (UNESCO, 2008).

4.1.3.1 BENEFITS OF AIED

The most promising uses of AI are in the area of learning delivery and assessment so that all learners everywhere, regardless of income, ability, or geography have access to high-quality learning, for example:

- **Freeing up and reallocating teacher time to more productive tasks.** Estimates suggest that 20% to 40% of current teacher hours (approximately 13 hours per week) are spent on activities that could be automated using existing technology powered by AI— grading, plagiarism detection, administration, and feedback. By offloading these tasks onto AI-designed applications, teachers could use this additional time for higher-level tasks that AI cannot replicate or automate, such as providing more effective support to individual students, modelling SEL skills, and inspiring, mentoring, and coaching students (Bryant, Heitz, Saurabh and Wagle, 2020, p. 2).
- **Temporarily addressing teacher shortages:** UNESCO (2020b) estimates that 69 million more teachers need to be recruited by 2030 to attain SDG4 (United Nations Educational Scientific and Cultural Organization, 2020b, p. 1). Where there are not enough teachers, AIED might be leveraged as an education delivery system to provide instruction to students via ITS, avatars, simulations, and other adaptive and personalised educational programmes.
- **Tutoring:** Intelligent tutoring systems (ITS) represent the most common applications of AI in education and have been adopted in education systems around the world for use with millions of students. ITS use knowledge tracing and machine learning to automatically adjust the level of difficulty and provide guidance, scaffolds, and feedback based on student

Although both are self-contained, computer-based 'tutoring' programmes, computer aided instruction (CAI) and intelligent tutoring systems (ITS) differ in their design.

CAI programmes are generally *answer-based systems* that provide hints, scaffolds and feedback at the level of the overall answer or 'status-feedback,' such as, for example, in the form of a score board or bar. CAI typically tends to be individualised and often do not incorporate AI principles.

ITS are an example of a *step-based system.* They provide hints, scaffolds, and feedback on every step that the student makes in solving a task. In particular, ITS offer status feedback as well as corrective feedback and, in some cases, conceptual feedback, which creates opportunities for higher-level thinking.

Step-based tutoring can be increasingly granular with sub-step-based feedback. These systems are typically designed using AI principles and are therefore more granular, adaptive, and personalised. Most adaptive and personalised learning programmes are AI based.

Box 21: *Computer-aided instruction vs. intelligent tutoring systems. Source: du Boulay, 2016* responses to questions or their progression in a task. Thus, learning is adapted to ensure that the student is able to learn the topic efficiently. Some ITS also capture and analyse data about the student's affective state, for example, monitoring their facial expressions and eye movement to infer the student's level of engagement (du Boulay, 2016; Buckley, Piacentini and von Davier, 2021).

As with CAI, with which ITS is often conflated, (see Box 21), ITS enjoy a robust body of research supporting their use for tutoring. Kulik and Fletcher's (2015) meta-review of 50 studies on ITS conclude that they can 'match the success' of human tutoring (p. 67), while other research has found a 'a significant advantage of ITS over teacher-led classroom instruction and non-ITS computer-based instruction' (Nesbit et al., 2014).

- **Helping learners with disabilities:** AI-driven applications are increasingly used to advance inclusion and equity in education. Artificial voices, many of which can be designed to match a student's original voice, can be used for students who are aphasic or have speech impediments, and AI-powered text-to-speech and speech-to-text applications can help students who are speech impaired or have mobility issues (UNESCO, 2019b). Using AI-powered voice assistants, visually impaired students can use voice commands to search for books in certain digital libraries and have the books read aloud to them. AI and augmented reality (AR)[53] applications can help deaf and hearing-impaired students read by translating texts into sign languages. For learners on the autism spectrum, speech-enabled robots can provide 'predictable mechanical interactions' to help these learners develop communication and social skills (Miao et al., 2021, p. 22).
- **Providing authentication:** AI, in the form of facial recognition, biometrics, voice recognition, keyboard dynamics, and text forensics, is increasingly being used by universities to verify candidates in examinations conducted via distance. To combat counterfeit diplomas or those granted by 'diploma mills,' AI-driven portfolios, secured by blockchain technologies, are increasingly being investigated as potential 'smart resumés.' These are essentially digital portfolios that include Non-Fungible Tokens (NFTs) (assets like photos or videos that are unique and not interchangeable) as well as student credentials from educational institutions, secured by blockchain to ensure authenticity. They are easily updatable, showcase higher-order skills and are far more comprehensive, detailed and secure than traditional resumés (Miao et al. 2021, p. 19; Pelletier et al. 2021; Buckley, Piacentini and von Davier, 2021).

53 Augmented reality is an 'interactive experience of a real-world environment where the objects that reside in the real world are enhanced by computer-generated perceptual information, across multiple sensory modalities, including visual, auditory, haptic, somatosensory and olfactory' (Wikipedia, n.d.)

- **Supporting writing:** AI tools, such as avatars, along with more sophisticated algorithms that provide feedback, are increasingly being used to help students with handwriting, writing, and composition and to improve discussions within learning management systems. AI-language generator tools, such as GPT-3 (which generated its own article for publication in *The Guardian*), could potentially be used to overcome writer's block (Ofgang, 2021; GPT-3, 2020).

AIED's benefits and potential are obviously considerable. Like all technologies, however, the use of AI raises numerous fundamental ethical, policy, and equity concerns.

4.1.3.2 CONCERNS REGARDING AIED

The first concern is about *biases* in AI. Algorithms are ultimately designed by human beings who have biases. Many of these biases have made their way into AI-powered applications by under-representing certain groups, generating outright sexist and racist language, and metastasising disinformation, including deep fakes (See Box 22). Open-source tools such as IBM's AI Fairness 360, Microsoft's Fairlearn, and the University of Chicago's Aequitas can help make detecting, mitigating, and correcting bias easier (Engler, 2021).

Second, when AI has been used to make inferences, as on large-scale examinations, it has proved problematic. In 2020, International Baccalaureate (IB) exam and the United Kingdom's Office of Qualifications and Examinations Regulation, used AI-powered grading to compensate for the absence of human scorers because of COVID-19. Tens of thousands of students from all over the world received grades that substantially and inexplicably deviated from their predicted grades. Reasons varied, such as a potentially flawed algorithm in the case of IB exams. Regarding the UK exams, the problem seemed

> AI can respond to any pattern, even those that by omission or commission, reflect gender, racial, and socioeconomic discrimination. Even the use of a student's address can cause models to perpetuate discrimination (Miao, Holmes, Huang, and Zhang, 2021).
>
> Algorithms perpetuate and scale these biases. For example, Google Open Images and Image Net have a combined total of over 725,000 images (as of July, 2021). Yet just 40% of images are of women and 5% show people who are dark skinned. Within these image databases, men are portrayed as skilled workers, and women are often portrayed wearing suggestive clothing. Images of light skinned people represent them as being higher status professionals, such as doctors (The Economist, 2021b, p. 77). Research also raises concerns of gender bias regarding virtual personal assistants, many of which, like Apple's Siri or Amazon's Alexa, use female voices. These voices often reproduce discriminatory stereotypes of women as flirtatious, submissive, and subservient to men compared to virtual personal assistants that use male voices (Adams, 2019).

***Box 22:** The many biases of AI*

to be that the algorithm incorporated biases towards private, fee-paying 'independent' schools in A-Level exams. (Evgeniou et al., 2020; Simonite, 2020).

The third concern relates to the role of the teacher. Every technology intervention discussed thus far yields better results when used as a complement to expert human instruction; AI-driven tools are probably no different. Yet, poor teaching plagues many education systems and education systems may be tempted to save on teacher salaries, typically the largest item in education budgets, and replace teachers with AI-driven computer programmes. Even if such a scenario does not come to pass, teacher roles may be marginalised if education systems forego helping teachers build new competencies around AIED (Miao et al., 2021, p. 18).

The fourth concern amplifies the ethical issues discussed earlier around data surveillance and big data. Constant data collection and monitoring of students by AI-based computer applications and the monopolisation of data by for-profit technology companies based in wealthy countries raise numerous issues around ownership of and profiting from personal data, security, and privacy, particularly in the Global South (Holstein et al., 2018; Lupton and Williamson, 2017). AIED is still new, and few governments have adopted ethical frameworks of responsible innovation or policies and regulations that balance effective and efficient innovations with protections for the agency, privacy, and security of teachers and students, particularly in the Global South and particularly among vulnerable and marginalised populations such as refugees, IDPs, and minorities (Holmes et al., 2018, p. 552).

Finally, as with all technology, AIED needs money, computing power and expertise to drive its development. Thus, the benefits of AI-powered technology threaten to widen an already large digital divide between teachers and students in rich countries and poor ones by benefitting students in wealthy countries versus those in poorer places who could ostensibly benefit most from AI's potential.

4.2 TECHNOLOGY TO SUPPORT LEARNING: FURTHER AREAS OF RESEARCH

This section raises multiple issues about technologies to support learning. First, the same technologies discussed in Sections 2 and 3—computer aided instruction, personalised learning programs, online classes, and mobile learning apps—allow students to directly learn from and with computers and that connect them to learning opportunities via distance. Yet they also collect data on these students, often among the world's most vulnerable, operating in countries with few or no regulations about ongoing surveillance and data collection. Thus, many of the technologies that serve as tools for learning and to deliver education run the risk of 'doing harm' to the very students they serve.

Second, while developments such as AI and big data can be powerful forces for improving equity and quality by targeting specific learning interventions and supports to students, the lack of both an understanding of each and a policy framework raises serious ethical and security issues for student privacy and safety.

These issues around security and ethics issue must be confronted as other technological innovations not mentioned here or in passing, such as the 'Internet of Things,' 3D printing, immersive learning, quantum computing, robotics, haptics, cybernetics, augmented reality, virtual reality, and measuring student brainwaves, are all in various stages of investigation, adoption, commercialisation, and use throughout the globe. While these emerging technology-based supports may offer educational benefits, as we've seen with AIED, data, and social media, they also present potential opportunities for harm and abuse and raise concerns about their development and use—issues about which the education community may only be marginally aware.

The world has witnessed the dark side of technology—cyberbullying, trolling, deep fakes, the proliferation of disinformation about ethnic minorities, about COVID-19, about vaccines—that has directly and indirectly resulted in harm to communities and individuals. The development of any technology should raise larger, more fundamental considerations: How can technological progress be coupled with educational policy to improve educational quality and equity while mitigating the harmful effects of technology? Whom do these technologies benefit? Whom do they hurt? How can teachers and students be given the tools to protect themselves from data harvesting and unwanted monitoring? Just because we can develop new kinds of technology, should we?

Third, the development and dissemination of OER, AIED, and data, while playing an important role towards improving equity and quality of educational opportunities in the Global South once again point to the unequitable nature of technology: With the possible exception of OER, these are digital developments constructed in the Global North and often imposed upon learners in the Global South. The risk is that wealthier students may profit most from their benefits, while poorer students may suffer most from their adverse effects.

This section concludes with a caution and proposed questions for further research. The flipside of these potentially promising supports for educational equity, quality, and inclusion outlined in this section—data harvesting, learning analytics, and AI—undermine student privacy, possibly student safety, and may subvert the credo of doing 'no harm' to students. Further research in these fields should focus on the ethics and security of such supports, the trade-offs between regulation and innovation, and the policy and technical considerations associated with these developments so that their benefits can be maximised while minimising their potential for abuse and harm.

Category	Suggested Research Questions
Open Education Resources	• How can OER support innovative learning design for underserved groups (e.g., indigenous, high poverty, transgender students and teachers) and link diversity, equity, and inclusion with deeper learning? (The William and Flora Hewlett Foundation, 2019a) • How can OER be institutionalised in such a way that it lowers the cost of digital content without stifling the development of local publishers of digital content?
Data	• What are the ethical obligations of private organisations (product developers) and public authorities (schools and universities involved in research) in terms of data collection and use? (Miao, Holmes, Huang, and Zhang, 2021, p. 20) • How can governments ensure stringent privacy and security around data collection, storage and use without stifling the minimal data collection needed for learning analytics and product improvement, development and further innovation (Miao, Holmes, Huang, and Zhang, 2021)?
Artificial Intelligence	• How can AI be leveraged to enhance education such that benefits are equitable to students and teachers in the Global South? • What are national and regional examples of ethical, inclusive and equitable use of AI in education? (Miao, Holmes, Huang and Zhang, 2021, p. 20)

Table 7: *Suggested questions for additional research (Section 4)*

CONCLUSION

As this think piece has shown, technology has expanded access, reallocated educational inputs, automated educational processes like assessment, delivered learning to refugee students, out-of-school youth, and teachers. It has helped to provide continuing education to many of the world's students during COVID and helped learners with a range of physical and learning disabilities access learning. In many cases, technology has shown statistically significant improved student learning outcomes. Technology has not lived up to much of the boosterism that creates unrealistic expectations but neither has it universally confirmed the cynicism and pessimism that often accompany its deployment.

However, as discussed throughout this think piece, although technology is an integral part of education its benefits are not distributed evenly. Thus, the noise around technology—issues of external validity, contradictory research results, differing points of view on its effectiveness—continues. There is much to laud about technology in education but there is even more to fix. This report concludes with a number of recommendations, some beyond the more defined research focus of this think piece, that may help policymakers, practitioners and researchers hone in on the signal of how to deliver quality learning more equitably. These recommendations are not new. They are often overlooked—and they are essential to ensuring that technology investments are not wasted.

First, education systems and those that fund them must design for equity and quality*.* Technology promises inclusion but for much of the world's students it delivers only exclusion. Digital, and more importantly, educational inclusion and equity, cannot happen without the most fundamental supports – access to a device, internet, software and a caring, well-trained teacher. All of this must be situated within an education system that is responsive to the needs of the communities that are often most excluded from technology provision. Designing for equity and quality is above all a political choice. It involves publicly and meaningfully proritising equity and quality within an education system; deliberately directing resources and investments to marginalised communities; developing initiatives that are tailored to local needs versus imposing one size fits all solutions; creating standards, helping educators attain these standards and holding them accountable for doing so; and consulting and collaborating with communities versus imposing external diktats.

Second, advances in educational technology must be coupled with changes in policy and strong implementation*.* The sins that characterise educational technology are often those of omission versus commission. Many Ministries of Education feel pressure to adopt technology but, like *Alice in*

Wonderland, are unsure of their destination or the best road to take. Technology initiatives must be driven by a vision; intended models and frameworks for teaching and learning; careful planning and investment; and detailed and fully funded implementation plans. They must ensure homeostasis among the various elements of the education system—technology, teachers, leadership, curriculum, assessment, and instruction—versus focusing on technology to the exclusion of these other elements. Without all of this, technology investments will inevitably and invariably fail.

Third, donors, governments, universities and private sector companies should work together to create utilisation-focused[54] research with longer timelines to capture the distal effects of technology. There's no question that ed tech initiatives need a strong foundation of evidence-based research, but Randomised Controlled Trials alone, as noted in Table 2, are insufficient, in part because of external validity issues, because they don't answer deeper, more qualitative questions, and because their methodologies and communication of findings may obscure more than they illuminate (Burns, 2020b). Educational technology initiatives need more research, on a range of constructs, but this research should be qualitative as well as quantitative, done *with* teachers and students, not just *on* them. They should capture the broader experiences and viewpoints of what technologies teachers and students are using and why, how, for what purposes and with what results (Christensen Institute, 2021).

Stakeholders—that is, technology companies, donors, and various educational implementers—should be mandated to share data, monitoring and evaluation indicators, and research evidence. This way the education community can begin to fill in gaps of what works and what doesn't in educational technology. Such practices can do much to education systems better understand technology, and as noted at the very beginning of this think piece, incorporate a broader array of evidence and experiences into technology planning and decision making (Wetzler and Bhatt, 2021).

Finally, governments and donors, not just technology companies should invest in research and development around ICTs in education. This involves the creation of system-level innovation funds that schools could access (Wetzler and Bhatt, 2021). For example, a percentage of education aid could be used to fund rigorous research and development into new models of technology-based instruction, testing and scaling low-cost, local-language and low-bandwidth tools for trial, revision and replication in particularly challenging contexts. This focus on research and development can be part of an overall continuum of research on educational technology—quantitative and qualitative

[54] The concept of 'utilisation focused evaluation' was developed by Michael Quinn Patton. More information about this approach can be found here.

research with their longer timelines combined with rapid prototyping and user testing with more condensed time frames.

Technology's imprint on education has been profound, as this think piece notes. But appreciation of its myriad benefits is often undercut by unrealistic expectations about its power to 'transform' education. Hardware and software cannot transform poorly funded and poorly run education systems that provide an inferior product to so many of the world's learners. That requires the efforts of caring and committed human beings, who keep students and their teachers, not machines, at the centre of their focus.

REFERENCES

Acosta, A., Palmer, I. and Romo-González, L. 2021. *Back to basics: quality in digital learning.* Washington, D.C., New America. https://www.newamerica.org/education-policy/reports/back-to-basics/

Adams, R. 2019. Artificial intelligence has a gender bias problem – just ask Siri. *The Conversation*. https://theconversation.com/artificial-intelligence-has-a-gender-bias-problem-just-ask-siri-123937

Africa Higher Education in Emergencies Network. n.d. Diploma in teacher education in emergencies. *Africa Higher Education in Emergencies Network*. https://aheen.net/programs/diploma-in-teacher-education-in-emergencies/

Afshari, M., Abu Bakar, K., Su Luan, W., Abu Samah, B. and Say Fooi, F. 2009, January. Factors affecting teachers use of information and communication technology. *International Journal of Instruction*, Vol. 2, No. 1, pp. 77–104.

Ainley, J. 1996. Purposeful contexts for formal notation in a spreadsheet environment. *Journal of Mathematical Behaviour*, Vol. 15, No. 4, pp. 405–422.

Aker, J. S., Ksoll, C. and Lybbert, T. 2012, October. Can mobile phones improve learning? evidence from a field experiment in Niger. *American Economic Journal: Applied Economics*, Vol. 4, No. 4, pp. 94-120. doi:10.1257/app.4.4.94

Alcatel-Lucent. 2012. *Building the benefits of broadband: how New Zealand can increase the social & economic impacts of high-speed broadband.* Wellington, NZ, Alcatel-Lucent. https://www.tmcnet.com/tmc/whitepapers/documents/whitepapers/2013/6687-building-benefits-broadband-how-new-zealand-increase-social.pdf

Ames, M.G. 2019. *The charisma machine: The life, death, and legacy of One Laptop per Child*. Cambridge, MA: MIT Press.

Anderson, M. and Perrin, A. 2018. Nearly one-in-five teens can't always finish their homework because of the digital divide. *Pew Research Centre.* https://www.pewresearch.org/fact-tank/2018/10/26/nearly-one-in-five-teens-cant-always-finish-their-homework-because-of-the-digital-divide/

Angeli, C. and Valanides, N. 2009. Epistemological and methodological issues for the conceptualization, development, and assessment of ICT-TPCK: advances in technology and pedagogical content knowledge (TPCK). *Computers and Education*, Vol. 52, pp. 154–168.

Angrist, J. and Lavy, V. 2002. New evidence on classroom computers and pupil learning. *Economic Journal*, Vol. 1, No. 12, pp. 735–765.

Angrist, N., Bergman, P., Brewster, C. and Matsheng, M. 2020. *Stemming learning loss during the pandemic: a rapid randomized trial of a low-tech intervention in Botswana.* Oxford, UK, Centre for the Study of African Economies, University of Oxford. (CSAE Working Paper Series 2020-13.)

Anzalone, S. and Bosch, A. 2005. *Improving educational quality through Interactive radio instruction: a toolkit for policy makers and planners.* Washington, DC: The World Bank. https://documents1.worldbank.org/curated/en/288791468035958279/pdf/357420AFRHD0521lkit1nov10501PUBLIC1.pdf

Ashman, H., Brailsford, H., Cristea, A. J., Sheng, Q. Z., Stewart, C., Toms, E. G. and Wade, V. 2014. The ethical and social implications of personalization technologies for e-learning. *Information and Management*, Vol. 51, pp. 819–832.

Asim, S., Chimombo, J., Chugunov, D. and Gera, R. 2017. *Moving teachers to Malawi's remote communities: a data-driven approach to teacher deployment.* Washington, D.C., World Bank Open Knowledge. (Policy Research Working Paper 8253.) https://openknowledge.worldbank.org/bitstream/handle/10986/28914/WPS8253.pdf

Banerjee, A. V., Cole, S., Duflo, E. and Linden, L. 2007. *Remedying education: evidence from two randomized experiments in India.* https://economics.mit.edu/files/804

BCcampus OpenEd. 2021. *BCcampus OpenEd*. https://open.bccampus.ca/

Bebell, D. and Burraston, J. 2014. Procedures and examples for examining a wide range of student outcomes from 1:1 student computing settings. *Profesorado. Revista de Currículum y Formación del Profesorado*, Vol. 18, No.3, pp. 137–160.

Bebell, D. and Kay, R. 2010. One to one computing: a summary of the quantitative results from the Berkshire Wireless Learning Initiative. *Journal of Technology, Learning, and Assessment*, Vol. 9, No. 2.

Bebell, D. and Pedulla, J. 2015. A quantitative investigation into the impacts of 1:1 iPads on early learner's ELA and math achievement. *Journal of Information Technology Education: Innovations in Practice*, Vol. 14, pp. 191–215. http://www.jite.org/documents/Vol14/JITEv14IIPp191-215Bebell1720.pdf

Bebell, D., Clarkson, A. and Burraston, J. 2014. Cloud computing: short term impacts of 1:1 computing in the sixth grade. *Journal of Information Technology Education: Innovations in Practice*, Vol. 13, pp. 129–151.

Bernard, R. M., Borokhovski, E., Richard F. Schmid, R. F., Waddington, D. I. and Pickup, D. I. 2019. Twenty-first century adaptive teaching and individualised learning operationalised as specific blends of student-centred instructional events: A systematic review and meta-analysis. *Campbell Systematic Review*, Vol. 15, No. 1–2. https://doi.org/10.1002/cl2.1017

Bloom, B.S. (1956) Taxonomy of educational objectives, handbook: the cognitive domain. New York, NY: David McKay.

BlueVoyant. 2021. *Cybersecurity in higher education 2021.* https://resources.bluevoyant.com/hubfs/2021%20Resources/Resource-final%20Cybersecurity%20In%20Higher%20Education%20Report.pdf

Bold, T., Kimenyi, M., Mwabu, G., Ng'ang'a, A. and Sandefur, J. 2013. *Scaling-up what works: experimental evidence on external validity in Kenyan education.* Washington, D.C., Centre for Global Development. https://www.cgdev.org/sites/default/files/archive/doc/kenya_rct_webdraft.pdf

Borzekowski, D. 2018. A quasi-experiment examining the impact of educational cartoons on Tanzanian children. *Journal of Applied Developmental Psychology*, Vol. 54, pp. 53–59. https://www.sciencedirect.com/science/article/abs/pii/S0193397317300850

Borzekowski, D. and Macha, J. E. 2010. The role of Kilimani Sesame in the healthy development of Tanzanian preschool children. *Journal of Applied Developmental Psychology*, Vol. 31, No. 4, pp. 298–305. 10.1016/j.appdev.2010.05.002

Boston University. 2021. *Boston University learning blocks (BULB)*. Boston, BU Digital Learning and Innovation. https://digital.bu.edu/product/bu-learning-blocks/

BRCK Education. 2015. *BRCK education and Kio Kit launch*. https://brck.com/brck-education-kio-and-kio-kit-launch/

Bryant, J., Heitz, C., Saurabh, S. and Wagle, D. 2020. *How artificial intelligence will impact K12 teachers.* New York, McKinsey & Company.

Buchel, K., Jakob, M., Kühnhanss, C., Steffen, D. and Brunetti, A. 2020. *The relative effectiveness of teachers and learning software: evidence from a field experiment in El Salvador.* Bern, CH, University of Bern. https://ideas.repec.org/p/bss/wpaper/36.html

Buckley, J., Piacentini, M. and von Davier, A. 2021. *Towards a new generation of assessment*. Presentation at Digital Education for a Strong Recovery: A Way Forward. Organisation for Economic Co-operation and Development.

Burns, M. 2006. Tools for the mind. *Educational Leadership*, Vol. 63, No. 4, pp. 48–53. http://www.ascd.org/ASCD/pdf/journals/ed_lead/el200512_burns.pdf

Burns, M. 2011. *Distance education for teacher training: modes, models and methods.* Washington, D.C., Education Development Center. http://go.edc.org/07xd

Burns, M. 2012. *Technology, teaching and learning: research, experience, and global lessons learned.* Washington, D.C., Education Development Center. https://www.edc.org/sites/default/files/uploads/Technology-Teaching-Learning-Research-Experience-Global-Lessons-Learned.pdf

Burns, M. 2013a. Success, failure or no significant difference: charting a course for successful educational technology integration. *International Journal of Emerging Technologies in Learning,* Vol. 8, No. 1, pp. 38–45. doi:http://dx.doi.org/10.3991%2Fijet.v8i1.2376

Burns, M. 2013b. Staying or leaving? designing for persistence in an online educator training program in Indonesia. *Open Learning: The Journal of Open and Distance Learning*, Vol. 28, No. 2, pp. 141–152. https://doi.org/10.1080/02680513.2013.851023

Burns, M. 2016. Ignoradas y subutilizadas: estrategias para incrementar la retención en programas en línea. G. K. Kelchtermans, J. Ormaza, D. Iturralde, S. Janssen and E. Campozano (eds.), *Formación de formadores y educación de calidad como generadora de cambio* (pp. 115–138). Leuven, BE: Katholieke Universiteit.

Burns, M. 2019a. For want of a good theory: considerations for technology integration in well-resourced schools. M. Classen. (Ed.), *A Closer Look at Educational Technology: Technology in a Globalising World*. New York, Nova Science Press, pp. 29–90.

Burns, M. 2020a, March. *Five beliefs that get in the way of project based learning—and how to address them.* PBL Works. https://www.pblworks.org/blog/five-beliefs-get-way-pbl-and-how-address-them

Burns, M. 2020b. From theory to use: making educational research more usable and useful for practitioners. *Annual Review of Comparative Education 2019 International Perspectives on Education and Society*, Vol. 39, pp. 47–53. doi:https://doi.org/10.1108/S1479-3679202039

Burns, M. and Dimock, K. 2007. *Technology as a catalyst for school communities: beyond boxes and bandwidth.* Lanham, MD: Rowman & Littlefield.

Burns, M., Orne, P. and Jhunjhunwala, N. (2020, June 10). *Will the COVID-19 pandemic speed a global embrace of online learning?* ICT Works: https://www.ictworks.org/covid19-digital-response-online-learning/

Burns, M., Santally, M., Roopesh, K., Sungkur, K. R., Juggurnath, B. and Rajabalee, Y. 2019b. *ICTs in secondary education in sub-Saharan Africa: policies, practices, trends and recommendations.* Toronto, CA: Mastercard Foundation. https://mastercardfdn.org/wp-content/uploads/2019/05/Education-in-Emergencies-FINAL.pdf

Carey Institute for Global Good. 2021. *Centre for learning in practice*. Carey Institute for Global Good. https://learning.careyinstitute.org/

Cayton-Hodges, G. A., Feng, G. and Pan, X. 2015. Tablet-based math assessment: what can we learn from math apps? international forum of educational technology. *Journal of Educational Technology & Society*, Vol. 18, No. 2, pp. 3–20.

Cennamo, K. S., Ross, J. D. and Ertmer, P. A. 2010. *Technology integration for meaningful classroom use: a standards-based approach.* Belmont, CA: Wadsworth, Cengage Learning.

Centre for Applied Special Technology. 2021. *Universal design for learning guidelines.* https://udlguidelines.cast.org/?utm_source=castsite&lutm_medium=web&utm_campaign=none&utm_content=aboutudl

Centre for Research and Innovation. 2010. *Are the new millennium learners making the grade? technology use and educational performance in PISA.* Paris: Organisation of Economic Cooperation and Development.

Centre for Research and Innovation in Education. 2007. *Giving knowledge for free: the emergence of open educational resources.* Paris" Organisation for Economic Co-operation and Development. https://www.oecd.org/education/ceri/38654317.pdf

Christensen Institute. 2021. *What is blended learning?* Boston, Clayton Christensen Institute. https://www.christenseninstitute.org/blended-learning/

Coble, S. 2021, April 20. School district's files leaked in $40m ransomware attack. *InfoSecurity Magazine*. https://www.infosecurity-magazine.com/news/broward-files-leaked-ransomware/

Cobo, C., Hawkins, R. and Rovner, H. 2020, March 31. *How countries across Latin America use technology during COVID19-driven school closures*. Washington, D.C., World Bank Blogs. https://blogs.worldbank.org/education/how-countries-across-latin-america-use-technology-during-covid19-driven-school-closures

Cohen, J. 1988. *Statistical power analysis for the behavioral sciences.* New York: Academic Press.

Cole, P. G. and Chan, L. 1994. *Teaching principles and practice.* New York: Prentice Hall.

Colvard, N. B., Watson, C. E. and Park, H. 2018. The impact of open educational resources on various student success metrics. *International Journal of Teaching and Learning in Higher Education,* Vol. 30, No. 2, pp. 262–276. https://www.isetl.org/ijtlhe/pdf/IJTLHE3386.pdf

Cooney, J. G. 1966. *The Potential uses of television in preschool education. a report to the Carnegie Corporation of New York.* New York: Carnegie Corporation.

Corporation for Public Broadcasting. 2015. *PBS: learn more the impact of America's largest classroom on learning.* Arlington, VA, PBS Education. https://bento.cdn.pbs.org/hostedbento-prod/filer_public/PBSLM-EDU/docs/PBS-Learn-More-Report.pdf

Corrales, C. 1995. *Adult basic education in Honduras: managing multiple channels. LearnTech case study 9.* Washington, D.C., Education Development Center and United States Agency for International Development.

Correa, T. 2015. Digital skills and social media use: how internet skills are related to different types of Facebook use among 'digital natives'. *Information, Communication & Society*, Vol. 19, No. 8, pp. 1095–1107. doi: 10.1080/1369118X.2015.1084023

Coursera for Campus. 2021. Teach your students the skills of the future. *Coursera for Campus.* https://www.coursera.org/campus/
Crawford, K. 2021. *Atlas of AI.* New Haven, Yale University Press.
Creative Associates International. 2002. *An evaluation of the Fundamental Quality in Education Level (FQEL) education program in Guinea.* Washington, D.C., United States Agency for International Development.
Cristia, J., Ibarrarán, P., Cueto, S., Santiago, A. and Severín, E. 2017. Technology and child development: evidence from the One Laptop per Child Program. *American Economic Journal: Applied Economics*, Vol. 9, No. 3, pp. 295–320.
Culbertson, S., Dimarogonas, J., Costello, K. and Lanna, S. (2019). *Crossing the digital divide: applying technology to the global refugee crisis.* Santa Monica, CA: RAND Corporation. https://www.rand.org/pubs/research_reports/RR4322.html
Culp, K. M., Honey, M. and Mandinach, E. B. 2005, July. A retrospective on twenty years of education technology policy. *Journal of Educational Computing Research*, Vol. 32, No. 3, pp. 279–307. https://doi.org/10.2190/7W71-QVT2-PAP2-UDX7
Darling-Hammond, L., Zielezinski, M. B. and Goldman, S. 2014, September. *Using technology to support at-risk students' learning*. Palo Alto, CA: Stanford University. https://edpolicy.stanford.edu/sites/default/files/scope-pub-using technologyreport.pdf
Da Silva Miguel, J. P. 2014. *Avaliar o impacto do portátil Magalhães no 1º Ciclo do Ensino Básico (CEB), no concelho de Matosinhos: fatores de (des)motivação nos agentes educativos.* Tese de Doutoramento em Educação Área de Especialização em Supervisão Pedagógica, Universidade Portaculense. http://repositorio.uportu.pt/jspui/bitstream/11328/1582/1/TDE%2051.pdf
De Melo, G., Machado, A. and Miranda, A. 2014. *IZA DP No. 8489: The impact of a One Laptop per Child Program on learning: evidence from Uruguay.* Bonn, DE, IZA Institute of Labour Economics. https://www.iza.org/publications/dp/8489/the-impact-of-a-one-laptop-per-child-program-on-learning-evidence-from-uruguay
Dettori, G., Garuti, R. and Lemut, E. 2001. From arithmetic to algebraic thinking by using a spreadsheet. T. R. R. Sutherland (ed.), *Perspectives on School Algebra.* Dordrecht, NL, Kluwer.
DeVynck, G. and Bergen, M. 2020, April 9. Google Classroom users doubled as quarantine spreads. *Bloomberg News*. https://www.bloomberg.com/news/articles/2020-04-09/google-widens-lead-in-education-market-as-students-rush-online
Dimock, K. V., Burns, M., Heath, M. and Burniske, J. 2001, December. *Applying technology to restructuring learning: how teachers use computers in technology assisted constructivist learning environments.* Austin, TX: Southwest Educational Development Laboratory.
Dobransky, K. and Hargittai, E. 2021, March. Piercing the pandemic social bubble: disability and social media use about COVID-19. *American Behavioral Scientist*, pp. 1–23. https://journals.sagepub.com/doi/10.1177/00027642211003146
Done, P. 2010, October 13. *Facebook is 'deliberately killing privacy', says Schneier.* London, Information Age. https://www.information-age.com/facebook-is-deliberately-killing-privacy-says-schneier-1290603/
Dooley, C. M., Ellison, T., Welch, M., Allen, M. and Bauer, D. 2016. Digital participatory pedagogy: digital participation as a method for technology integration in curriculum. *Journal of Digital Learning in Teacher Education*, Vol. 32, No. 2, pp. 52-62. https://www.tandfonline.com/doi/abs/10.1080/21532974.2016.1138912
Dreesen, T., Akseer, S., Brossard, M., Dewan, G., Giraldo, J., Kamei, A., Mizunoya, S. and Ortiz, J. S. 2020. *Innocenti research brief*: *promising practices for equitable remote learning: emerging lessons from COVID-19 education responses in 127 countries.* Paris, UNICEF. https://reliefweb.int/sites/reliefweb.int/files/resources/IRB%202020-10.pdf
du Boulay, B. 2016. *Artificial intelligence as an effective classroom assistant.* Brighton, UK, University of Sussex. http://users.sussex.ac.uk/~bend/papers/meta-reviewsIEEEV5.pdf
Editrice Morcelliana. 2020, March. *Essere a Scuola fascicolo speciale 'La scuola a casa.'* Brescia, IT, Editrice Morcelliana. http://www.morcelliana.net/essere-a-scuola/3887-essere-a-scuola-fascicolo-speciale-la-scuola-a-casa.html
EdSurge. 2020, March 11. *Edtech investment around the world in 2020.* https://www.edsurge.com/news/2021-03-11-edtech-investment-around-the-world-in-2020-infographic

Education 2030. 2015. *Incheon declaration and framework for action for the implementation of sustainable development goal 4: ensure inclusive and equitable quality education and promote lifelong learning.* https://unesdoc.unesco.org/ark:/48223/pf0000245656

Education Development Center and Stanford Research Institute. 2021. *Mahsi'choo for the Info! Molly of Denali teaches children about informational text.* Washington, D.C., Corporation for Public Broadcasting. https://www.edc.org/sites/default/files/uploads/EDC-SRI-Mahsi-choo-Info-Summary.pdf

Engler, A. (2021, August 10). How open-source software shapes AI policy. *Brookings Institution's Artificial Intelligence and Emerging Technology (AIET) Initiative.* https://www.brookings.edu/research/how-open-source-software-shapes-ai-policy/

Ertmer, P. A. 1999, December. Addressing first-and second-order barriers to change: strategies for technology integration. *Educational Technology Research and Development*, Vol. 47, pp. 47–61. https://doi.org/10.1007/BF02299597

Ertmer, P. A. 2005. Teacher pedagogical beliefs: the final frontier in our quest for technology integration? *Educational Technology Research and Development*, Vol. 53, No. 4, pp. 25–40. http://dx.doi.org/10.1007/BF02504683

Ertmer, P. A. and Ottenbreit-Leftwich, A. T. 2010. Teacher technology change: how knowledge, confidence, beliefs, and culture intersect. *Journal of Research on Technology in Education*, Vol. 42, No. 3, pp. 255–284.

Ertmer, P. A., Gopalakrishnan, S. and Ross, E. M. 2001. Technology-using teachers: comparing perceptions of exemplary technology use to best practice. *Journal of Research on Computing in Education*, Vol. 33, No. 5, pp. 423–435.

Ertmer, P. A., Ottenbreit-Leftwich, A. T., Sadik, O., Sendurur, E. and Sendurur, P. 2012. Teacher beliefs and technology integration practices: a critical relationship. *Computers in Education*, Vol. 59, pp. 423–435.

European Union. 2021. *Complete Guide to GDPR Compliance.* https://gdpr.eu/

Evans, D. K. and Yuan, F. 2020. *How big are effect sizes in international education studies?* Washington, D.C., Centre for Global Development. (CGD Working Paper 545.) https://www.cgdev.org/sites/default/files/how-big-are-effect-sizes-international-education-studies.pdf

Evgeniou, T., Hardoon, D. R. and Ovchinnikov, A. 2020, August 13. What happens when AI is used to set grades? *Harvard Business Review*. https://hbr.org/2020/08/what-happens-when-ai-is-used-to-set-grades

Feldstein, M. 2013, December. What faculty should know about adaptive learning. *American Federation of Teachers On Campus*. https://www.aft.org/sites/default/files/periodicals/oc_winter1314.pdf

Fleisch, B., Gultig, J., Allais, S. and Maringe, F. 2019. *Background paper on secondary education in Africa: curriculum reform, assessment and national qualifications frameworks.* Toronto, Mastercard Foundation. https://mastercardfdn.org/wp-content/uploads/2019/06/Curriculum-Reform-Assessments-National-Qualifications-Frameworks-FINAL.pdf

Fleming, K. 2021. *I-Flex: a new teaching modality for post-pandemic recovery.* Sykesville, MD, Core Education LLC. https://www.coreeducationllc.com/blog2/wp-content/uploads/2021/03/I-Flex-A-New-Teaching-Modality-for-Post-Pandemic-Recovery-Final.pdf

France, P. E. 2021, May 17. Four steps for humanising personalised learning. Portland, OR, *EdSurge*. https://www.edsurge.com/news/2021-05-17-4-steps-for-humanizing-personalised-learning

Fuchs, T. and Wößmann, L. 2005. *Computers and student learning: bivariate and multivariate evidence on the availability and use of computers at home and at school.* https://ideas.repec.org/p/ces/ceswps/_1321.html (CESifo Working Paper Series 1321.)

Gallion, J. C. 2018. *Performance audit report North Dakota university system open educational resources report No. NP-007-17.* Fargo, ND: Office of the State Auditor North Dakota University System Performance Audit. https://www.nd.gov/auditor/sites/www/files/documents/Reports/State/2018%20NDUS%20-%20Performance%20Audit%20-%20Open%20Educational%20Resources.pdf

Gebhardt, E., Thomson, S., Ainley, J., & Hillman, K. J. (2019). Teacher gender and ICT. In *Gender Differences in Computer and Information Literacy* (pp. 53-68). https://link.springer.com/chapter/10.1007/978-3-030-26203-7_5

Gee, J. P. and Shaffer, D. W. 2010. *Looking where the light is bad: video games and the future of assessment.* Madison, WI: University of Wisconsin-Madison. (Epistemic Games Group Working Paper No. 2010-02.)

Geena Davis Institute on Gender and Media. (2020). *See Jane 2020 TV.* Geena Davis Institute on Gender and Media. https://seejane.org/wp-content/uploads/2020-tv-historic-screen-time-speaking-time-for-female-characters-report.pdf

Global System for Mobile Communications. 2016. *Mobile privacy principles: promoting consumer privacy in the mobile ecosystem.* London: GSM Association. https://www.gsma.com/publicpolicy/wp-content/uploads/2012/03/GSMA2016_Guidelines_Mobile_Privacy_Principles.pdf

Glossary of Education Reform. 2016. *Student engagement*. https://www.edglossary.org/student-engagement/

Goel, A. 2016, November 1. *A teaching assistant named Jill Watson: TEDx San Francisco*. https://www.youtube.com/watch?v=WbCguICyfTA

Google for Education. 2021. *Guardian's guide to tools for children with disabilities during distance learning.* https://docs.google.com/document/d/1-MfcIYSfLuH5rR8BBxNKxpsPEG_4lX5PcqeG-6FSJcg/preview

Gouli, E., Gogoulou, A. and Grigoriadou, M. 2003. A coherent and integrated framework using concept maps for various educational assessment functions. *Journal of Information Technology Education*, Vol. 2, pp. 215–240.

GPT-3. 2020, September 8. A robot wrote this entire article. are you scared yet, human? *The Guardian*. https://www.theguardian.com/commentisfree/2020/sep/08/robot-wrote-this-article-gpt-3

Grant, C. and Morrell, A. 2021, April 6. Low-tech home-based learning support for children in Kano State, Nigeria. *UKFIET The Education and Development Forum*. https://www.ukfiet.org/2021/low-tech-home-based-learning-support-for-children-in-kano-state-nigeria/

Green, K., Pinder-Grover, T. and Millunchick, J. M. 2012. Impact of screencast technology: connecting the perception of usefulness and the reality of performance. *Journal of Engineering Education*, Vol. 101, pp. 717–737.

Griffiths, R., Mislevy, J., Wang, S., Ball, A., Shear, L. and Desrochers, D. 2020. *OER at scale: the academic and economic outcomes of achieving the dream's OER degree initiative.* Menlo Park, CA: SRI Education.

GSMA. 2020. *Connected women: Mobile gender gap report: 2020.* https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2020/05/GSMA-The-Mobile-Gender-Gap-Report-2020.pdf

GSMA. 2019. *Connected society: State of mobile internet connectivity.* https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2019/07/GSMA-State-of-Mobile-Internet-Connectivity-Report-2019.pdf

Guryan, J., Ludwig, J., Bhatt, M. P., Cook, P. J., Davis, J.M.V., Dodge, K., Frakas, G., Freyer, Jr., R. G.; Mayer, S., Pollack, H. and Steinberg, L. 2021. *Not too late: improving academic outcomes among adolescents.* Cambridge, MA. (NBER Woking Paper No. 28531.) https://www.nber.org/papers/w28531

Gustafsson-Wright, E., Osborne, S. and Sharma, A. 2021, May 6. *How can real-time performance data lead to better education outcomes?* Washington, D.C., Brookings. https://www.brookings.edu/blog/education-plus-development/2021/05/06/how-can-real-time-performance-data-lead-to-better-education-outcomes/

Harris, J., Mishra, P. and Koehler, M. J. 2009. Teachers' technological pedagogical content knowledge and learning activity types: Curriculum-based technology integration reframed. *Journal of Research on Technology in Education*, Vol. 41, No. 4, pp. 393–416.

Haßler, B., Major, L. and Hennessy, S. 2016. Tablet use in schools: A critical review of the evidence for learning outcomes. *Journal of Computer Assisted Learning*, Vol. 32, No. 2, pp. 139–156.

Hattie, J. 2017. *Visible Learning Plus 250+ influences on student achievement*. Visible Learning. https://visible-learning.org/wp-content/uploads/2018/03/VLPLUS-252-Influences-Hattie-ranking-DEC-2017.pdf

Heflin, H., Shewmaker, J. and Nguyen, J. 2017. How does mobile technology affect the demonstration of critical thinking in writing products created during collaborative learning? *Computers and Education*, 107, pp. 91–99. https://www.sciencedirect.com/science/article/abs/pii/S0360131517300064

Hegarty, S. 2012, April 27. How soap operas changed the world. *British Broadcasting Corporation*. http://bbc.in/1tn1mjJ

Heinrich , P. 2010. *The IPAD as a tool for education: a study of the introduction of iPADs at Longfield Academy.* Winchester, National Association of Advisors for Computers in Education.

Hennessy, S., Jordan, K., Wagner, D. and Ed Tech Hub Team. 2021. *Problem analysis and focus of EdTech Hub's Work: technology in education in low- and middle-income countries.* EdTech Hub. (Working Paper 7.) https://docs.edtechhub.org/lib/PBXBB7LF

Hew, K. and Brush, T. 2007, June. Integrating technology into K-12 teaching and learning: current knowledge gaps and recommendations for future research. *Educational Technology Research and Development*, Vol. 55, No. 3, pp. 223–252.

Hill, C. J., Bloom, H. S., Black, A. R. and Lipsey, M. W. 2008. Empirical Benchmarks for interpreting effect sizes in research. *Child Development Perspectives*, Vol. 2, No. 3, pp. 172–177. doi:10.1111/j.1750-8606.2008.00061.x

Ho, J. and Thukral, H. 2009. *Tuned in to student success: assessing the impact of interactive radio instruction for the hardest to reach.* Washington, D.C., Education Development Center, Inc. http://idd.edc.org/news/articles.php?id=277

Holder, B. 2007. An investigation of hope, academics, environment, and motivation as predictors of persistence in higher education online programs. *internet & Higher Education*, Vol. 10, No. 4, pp. 245–260. https://www.sciencedirect.com/science/article/abs/pii/S1096751607000528

Holmes, W., Bektik, D., Whitelock, D. and Woolf, B. P. 2018. Ethics in AIED: who cares? C. Penstein Rosé, R. Martínez-Maldonado, H.U. Hoppe, R. Luckin, M. Mavrikis, K. Porayska-Pomsta, B. McLaren and B. du Boulay (eds.), *Lecture Notes in Computer Science*, pp. 551–553. London: Springer International Publishing.

Holon IQ. 2021. *2021 Global learning landscape: mapping the future of education*. Holon IQ. https://www.globallearninglandscape.org/HolonIQ-2021-Global-Learning-Landscape-Handbook.pdf

Holstein, K., McLaren, B. M. and Aleven, V. 2018. Student learning benefits of a mixed-reality teacher awareness tool in AI-enhanced classrooms. C. Penstein Rosé, R. Martínez-Maldonado, H. U. Hoppe, R. Luckin, R., M. Mavrikis, K. Porayska-Pomsta, B. McLaren and B. du Boulay (eds.), *Proceedings of the 19th International Conference, AI in Education 2018*, Vol. 10947, pp. 154–168. London, Cham, Springer International Publishing.

Hord, S., Rutherford , W. L., Huling-Austin, L. and Hall, G. 2006. *Taking charge of change.* Austin, TX: Southwest Educational Development Laboratory.

Inan, F. A. and Lowther, D. L. 2010. Factors affecting technology integration in K-12 classrooms: a path model. *Education Technology Research and Development*, Vol. 58, pp. 137–154.

Industry Research. 2021, March. *Global screen recording software market size, status and forecast 2021-2027.* https://www.industryresearch.co/global-screen-recording-software-market-17771217

Inksater, K. 2017. *Evaluation of the project 'strengthening teachers' skills to meet the needs of 21st century learners – phase 2.'* Washington, D.C.: Organization of American States.

Institut national de la statistique et des études économiques. 2019. *Statistiques et études*. https://www.insee.fr/fr/statistiques

Institute of Electrical and Electronics Engineers. 2020. IEEE learning with MOOCS (LWMOOCS). https://www.ieee.org/

Inter-American Development Bank. 2009, January. Brazilian soap operas shown to impact social behaviours. *Inter-American Development Bank News*. https://www.iadb.org/en/news/brazilian-soap-operas-shown-impact-social-behaviors

International Association of Universities. 2020. *IAU global survey on the impact of COVID-19 on higher education around the world.* Paris, International Association of Universities. https://www.iau-aiu.net/IAU-Global-Survey-on-the-Impact-of-COVID-19-on-Higher-Education-around-the

International Initiative for Impact Evaluation. (2019). *What is the impact of education programmes on children's learning and school participation?* 3ie Systematic Review Brief. https://www.3ieimpact.org/sites/default/files/2019-05/srs7-eer-policy-brief-web.pdf

International Telecommunication Union. 2010. *World telecommunication/ICT development report.* https://www.itu.int/ITU-D/ict/publications/wtdr_10/: International Telecommunication Union

Irvine, V. 2021. The landscape of emerging modalities. *EDUCAUSE Review,* No. 4, pp. 40–58. https://er.educause.edu/-/media/files/articles/2020/10/er20_4103.pdf

Jackson, C. K. and Bruegmann, E. 2009. *Teaching students and teaching each other: the importance of peer learning for teachers.* Washington, D.C., National Bureau of Economic Research. (Working Paper No. 15202.) https://www.nber.org/papers/w15202

Johnson, J. 2008. Can a laptop change how the world teaches? *Knowledge Quest*, Vol. 36, No. 4, pp. 72–73.

Johnson, K. 2021, June 17. The efforts to make text-based Ai less racist and terrible. *Wired*. https://www.wired.com/story/efforts-make-text-ai-less-racist-terrible

Jonassen, D. H., Carr, C. S. and Yueh, H.-P. 1998. Computers as mindtools for engaging learners in critical thinking. *TechTrends*, Vol. 3, No. 2, pp. 4–32.

Jones, K. 2005. Using spreadsheets in the teaching and learning of mathematics: a research bibliography. *MicriMath*, Vol. 21, No. 1, pp. 30–31.
Kazempour, M. 2009. Impact of inquiry-based professional development on core conceptions and teaching practices: a case study. *Science Education*, Vol. 18, No. 2, pp. 56–68.
Keegan, D. 1996. *Foundations of distance education,* 3rd ed. London, UK: Routledge.
Kennedy, M. M. 2016. How does professional development improve teaching? *Review of Educational Research*, Vol. 86, No. 4, pp. 1–36. https://journals.sagepub.com/doi/10.3102/0034654315626800
Kizilcec, R. F., Reich, J., Yeomans, M., Dann, C., Brunskill, E., Lopez, G., Turkay, S., Williams, J.J. and Tingley, D. 2020, June 30. Scaling up behavioral science interventions in online education. *Proceedings of National Academy of Sciences of the United States of America*, Vol. 117, No. 26. https://www.pnas.org/content/117/26/14900
Klein, A. 2021. 'A year of tremendous growth.' how the pandemic forced teachers to master technology. *Education Week Special Report*. https://www.edweek.org/technology/a-year-of-tremendous-growth-how-the-pandemic-forced-teachers-to-master-technology/2021/04
Knowles, M. (1975). *Self-directed learning: A guide for learners and teachers*. New York, NY: Association Press.
Kulik, J. 2003. *Effects of using instructional technology in elementary and secondary schools: what controlled evaluation studies say.* Arlington, VA: SRI International.
Kulik, J. A. and Fletcher, J. D. 2015. Effectiveness of intelligent tutoring systems: a meta-analytic review. *Review of Educational Research*, Vol. 86, No. 1, pp. 1–37. https://journals.sagepub.com/doi/abs/10.3102/0034654315581420
La Tercera.com. 2020. Canales Enseña, nuevas formas gratuitas de educar a distancia. *La Tercera*. https://www.latercera.com/laboratoriodecontenidos/noticia/canales-ensena-nuevas-formas-gratuitas-de-educar-a-distancia/JFDWWNDIUZDTVCATIXMIAQ55OE/
Latchem, C. and Jung, I. 2010. *Distance and blended learning in Asia.* New York, Routledge.
Learning Exchange. 2011. *iPads in schools: use testing.* Parramata, AU, Catholic Education Diocese of Parramata.
Lei, J. and Zhao, Y. 2008. One-to-one computing: what does it bring to schools? *Journal of Educational Computing Research*, Vol. 39, No. 2, pp. 97–122. https://journals.sagepub.com/doi/10.2190/EC.39.2.a
Leigh, S. 1995. *Changing times in South Africa: remodeling interactive learning.* Washington, D.C., United States Agency for International Development.
Leithwood, K., Seashore, L. K., Anderson, S. and Wahlstrom, K. 2004. *Review of research: how leadership influences student learning.* New York, Wallace Foundation: https://www.wallacefoundation.org/knowledge-center/Documents/How-Leadership-Influences-Student-Learning.pdf
Lewis, G. M. 2014. Implementing a reform-oriented pedagogy: challenges for novice secondary mathematics teachers. *Mathematics Education Research Journal*, Vol. 26, pp. 399–419.
Li, S. C. and Choi, T. H. 2014. Does social capital matter? a quantitative approach to examining technology infusion in schools. *Journal of Computer Assisted Learning*, Vol. 30, No. 1, pp. 1–16.
Lipsey, M. W., Puzio, K., Yun, C., Hebert, M. A., Steinka-Fry, K., Cole, M. W., Roberts, M., Anthony, K. S. and Busick, M. D. 2012. *Representation of the effects of education interventions into more readily interpretable forms.* Washington D.C., National Centre for Special Education Research, Institute of Education Sciences, U.S. Department of Education. https://ies.ed.gov/ncser/pubs/20133000/pdf/20133000.pdf
Livingstone, S. 2012. Critical reflections on the benefits of ICT in education. *Oxford Review of Education*, Vol. 38, No. 1, pp. 9–24. https://www.tandfonline.com/doi/abs/10.1080/03054985.2011.577938
Lloyd, S. A. and Robertson, C. L. 2012. Screencast tutorials enhance student learning of statistics. *Teaching of Psychology*, Vol. 39, No. 1, pp. 67–71.
Lupton, D. and Williamson, B. 2017. The datafied child: dataveillance of children and implications for their rights. *New Media & Society*, Vol. 19, No. 5, pp. 780–794.
Lynch, P., Singal, N. and Francis, G. 2021. *EdTech for learners with disabilities in primary school settings in LMICs: a systematic literature review.* https://docs.edtechhub.org/lib/XJ42VUQG
Macleod, E. 2021, March. Data and evidence on forced displacement: reflections on progress and challenges. *Force Migration Review: Mental health and psychosocial support issue*, Vol. 66, pp. 46–50.
Maddux, C. D., Johnson, D., & Willis, J. (2001). *Educational Computing: Learning with Tomorrow's Technologies, 3rd Edition.* London, U.K.: Pearson.
Major, L. and Francis, G. A. 2020. *Technology-supported personalised learning: a rapid evidence review.* EdTech Hub Rapid Evidence Review. https://docs.edtechhub.org/lib/A2II5ZV7

Mares, M. L. and Pan, Z. 2013. Effects of Sesame Street: a meta-analysis of children's learning in 15 countries. *Journal of Applied Developmental Psychology*, Vol. 34, No. 3, pp. 140–151. https://www.sciencedirect.com/science/article/abs/pii/S0193397313000026

Marshall, S. 2010. Change, technology and higher education: are universities capable of organisational change? *ALT-J Association for Learning Technology Journal*, Vol. 18, No. 3, 179–192. doi: 10.1080/09687769.2010.529107

Martin, F., Polly, D. and Ritzhaupt, A. 2020, September 8. *Bichronous online learning: blending asynchronous and synchronous online learning*. EDUCAUSE. https://er.educause.edu/articles/2020/9/bichronous-online-learning-blending-asynchronous-and-synchronous-online-learning

Martínez, A., Adib, L., Senne, F. and Pérez, R. 2020. Contexto educativo: Uso escolar y mediación docente. In *Infancia y adolescencia en la era digital. Un informe comparativo de los estudios de Kids Online del Brasil, Chile, Costa Rica y el Uruguay* (pp. 55–76).

Marzano, R., Pickering, D. and Pollock, J. E. 2001. *Classroom instruction that works: research-based strategies for increasing student achievement.* Alexandria, VA: Association of Supervision and Curriculum Development.

Masele, J. J. and Rwehikiza, D. P. 2021. Applications of social media for promoting higher learning institutions' activities in Tanzania. *International Journal of Education and Development Using Information and Communication Technology*, Vol. 17, No. 2, pp. 37–54.

Mastercard Foundation. 2020, July. *Secondary Education in Africa: preparing youth for the future of work.* Toronto, Mastercard Foundation. https://www.issuelab.org/resources/35972/35972.pdf

Masters, G. 2021, June 21. Computer adaptive testing – challenging traditional thinking. *Teacher Evidence+Insight+Action*. https://www.teachermagazine.com/au_en/articles/computer-adaptive-testing-challenging-traditional-thinking

Mathewson, T. G. and Butrymowicz, S. 2021, May 20. Ed tech companies promise results, but their claims are often based on shoddy research. *The Hechinger Report*. https://hechingerreport.org/ed-tech-companies-promise-results-but-their-claims-are-often-based-on-shoddy-research/

McEwan, P. J. 2015, September. Improving learning in primary schools of developing countries: a meta-analysis of randomized experiments. *Review of Educational Research*, Vol. 85, No. 3, pp. 353–394. doi:10.3102/0034654314553127

McMurtrie, B. 2021, June 24. Frustrated and exhausted by a year of remote teaching? you're not alone. *Chronicle of Higher Education*. https://www.chronicle.com/newsletter/teaching/2021-06-24

Means, B., Toyama, Y., Murphy, R., Bakia, M. and Jones, K. 2009. *Evaluation of evidence-based practices in online learning: a meta-analysis and review of online learning studies.* Washington, D.C., United States Department of Education.

Miao, F., Holmes, W., Huang, R. and Zhang, H. 2021. *AI and education: guidance for policymakers.* Paris, United Nations Educational, Scientific and Cultural Organization.

Mitchell, C. 2020, September. Bilingualism and remote learning. *Education Week Spotlight.* https://epe.brightspotcdn.com/5d/fe/b3d99a0c4532b0b1ea90aafaf477/spotlight-on-bilingualism-and-remote-learning-2020sponsored.pdf

Mo, D., Zhang, L., Luo, L., Qu, Q., Huang, W., Wang, J., Qiao, Y., Boswell, M. and Rozelle, S. 2014. Integrating computer-assisted learning into a regular curriculum: evidence from a randomised experiment in rural schools in Shaanxi. *Journal of Development Effectiveness*, Vol. 6, No. 3, pp. 300–323. doi: 10.1080/19439342.2014.911770

Moeller, B., and Reitzes, T. (2011). *Integrating technology with student-centered learning.* Quincy, MA: Nellie Mae Educational Foundation.

Molnar, A. (Ed.), Miron, G., Barbour, M.K., Huerta, L., Shafer, S.R., Rice, J.K., Glover, A., Browning, N., Hagle, S. and Boninger, F. 2021. *Virtual schools in the U.S. 2021.* Boulder, CO: National Education Policy Centre. http://nepc.colorado.edu/publication/virtual-schools-annual-2021

MOOC List. n.d. Refugees. *MOOC List*. https://www.mooc-list.com/tags/refugees

Morning Consult. 2021, February. *IBM education ransomware study.* New York, Morning Consult. https://filecache.mediaroom.com/mr5mr_ibmnews/189762/IBM_Embargo%20Feb.%204_6%20AM%20ET_IBM%20Education%20Ransomware%20Study.pdf

Muralidharan, K., Singh, A. and Ganimian, A. J. 2016. *Disrupting education? experimental evidence on technology-aided instruction in India.* Cambridge, MA: National Bureau of Education Research. (Working Paper 22923.) http://www.nber.org/papers/w22923

Mwantimwa, K., Mwabungulu, E. and Kassim, M. 2021. Academic staff and researchers' use of electronic resources in Tanzania: a comparative study. *International Journal of Education and Development using Information and Communication Technology*, Vol. 17, No. 2, pp. 55–75.

Mwareya, R. and Simango, A. 2021, June 25. How an 'unqualified' 27-year-old Zimbabwean teacher created a top tutoring academy on WhatsApp. *Rest of World*. https://restofworld.org/2021/learning-on-the-last-mile

Nakashima, R. 2018, August 13. AP exclusive: Google tracks your movements, like it or not. *Associated Press*. https://apnews.com/article/north-america-science-technology-business-ap-top-news-828aefab64d4411bac257a07c1af0ecb

National Centre for Education Statistics. 2021. Common core of data: America's public schools: Table 3: number of virtual schools, total state enrolment, total virtual school enrolment, and virtual school enrolment as a percentage of state total enrolment: School year 2019–2020. *National Centre for Education Statistics*. https://nces.ed.gov/ccd/tables/201920_Virtual_Schools_table_3.asp

National Centre for Learning Disabilities. 2019, June. *Inclusive technology in a 21st century learning system.* https://www.ncld.org/research/inclusive-technology-in-a-21st-century-learning-system

National Centre on Accessible Educational Materials. 2020. *Creating NIMAS files.* Wakefield, MA, National Centre on Accessible Educational Materials: https://aem.cast.org/binaries/content/assets/common/publications/aem/creating-nimas-files-2021.pdf

National Reading Panel. 2000. *Teaching children to read: an evidence-based assessment of the scientific research literature on reading and its implications for reading instruction.* Bethesda, MD: National Institute for Child Health and Child Development.

Nesbit, J. C., Adesope, O. O., Liu, Q. and Ma, W. 2014. How effective are intelligent tutoring systems in computer science education? *IEEE 14th International Conference on Advanced Learning Technologies (ICALT).* Athens, Greece.

Newhouse, C. 2013, December. Learning with portable digital devices in Australian schools: 20 years on! *Australian Educational Researcher*, Vol. 41, pp. 471–483.

Newman, L. H. 2021, April 26. The new iOS update lets you stop ads from tracking you—so do it. *Wired*. https://www.wired.com/story/ios-app-tracking-transparency-advertising/

Nicas, J. 2021, June 15. The cloud and the law: a primer. *The New York Times*, pp. B1, B4.

OER Africa. 2021. *OER Africa*. https://www.oerafrica.org/

Office of Educational Technology. (2017). *Reimagining the role of technology in education: 2017 national education technology plan update.* Washington, D.C.: U.S. Department of Education. https://tech.ed.gov/files/2017/01/NETP17.pdf

Ofgang, E. 2021, April 19. AI writing programs are getting better. is that a good thing? *Tech & Learning*. https://www.techlearning.com/news/ai-writing-programs-are-getting-better-is-that-a-good-thing?

Olson, J., Codde, K., Demaagd, K., Tarkelson, E., Sinclair, J., Yook, S. and Egidio, R. 2011. *An analysis of e-learning impacts & best practices in developing countries with reference to secondary school education in Tanzania.* Lansing, MI, Michigan State University.

Organisation for Economic Cooperation and Development. 2015. *Students, computers and learning: making the connection.* Paris, PISA, OECD Publishing. https://www.oecd-ilibrary.org/education/pisa_19963777

Organisation for Economic Cooperation and Development. 2018a. *New technologies and 21st century children: recent trends and outcomes.* Paris, OECD. (OECD Education Working Paper No. 179.)

Organisation for Economic Cooperation and Development. 2018b. *2018 TALIS results: teachers and school leaders as lifelong learners and valued professionals.* TALIS: The OECD Teaching and Learning International Survey. https://www.oecd.org/education/talis/

Organisation for Economic Cooperation and Development. 2020a. *Achieving the new curriculum for Wales, implementing education policies.* Paris, OECD Publishing. https://doi.org/10.1787/4b483953-en

Organisation for Economic Cooperation and Development. 2020b. *Learning remotely when schools close: how well are students and schools prepared? insights from PISA.* Paris, OECD. https://read.oecd-ilibrary.org/view/?ref=127_127063-iiwm328658&title=Learning-remotely-when-schools-close

Orwenjo, D. O. and Kanan, F. 2018. Challenges of adopting open educational resources (OER) in Kenyan secondary schools: the case of open resources for English language teaching. *Journal of Learning for Development*, Vol. 5, No. 2, pp. 148–162.

Pakyamian, B. 2021, March 29. What's driving growth in the ed tech market? *Government Technology*. https://www.govtech.com/education/k-12/whats-driving-growth-in-the-ed-tech-market.html

Pane, J. F., Steiner, E. D., Baird, M. D., Hamilton, M. S. and Pane, J. D. 2017. *Informing progress: insights on personalised learning implementation and effects.* Santa Monica, CA: RAND Corporation, RR-2042-BMGF. http://www.rand.org/t/RR2042

Pedró, F. 2012. Trusting the unknown: the effects of technology use in education. S. Dutta and B. Bilbao-Osorio (eds.), *The Global Information Technology Report* (pp. 135–148). Geneva, World Economic Forum. http://www3.weforum.org/docs/Global_IT_Report_2012.pdf

Pelletier, K., Brown, M., Brooks, D. C., McCormack, M., Reeves, J., Arbino, N., Bozkurt, A., Crawford, S., Czerniewicz, L., Gibson, R., Linder, K., Mason, J. and Mondelli, V. 2021. *2021 EDUCAUSE horizon report: teaching and learning edition.* Boulder, CO: EDUCAUSE. https://library.educause.edu/-/media/files/library/2021/4/2021hrteachinglearning.pdf

Pereira, R., Seki, J., Palharini, B., Neto, J. C., Silva, A. C., Damin, W. and Martins, B. O. 2017. Modelagem matemática e tecnologias digitais educacionais: Possibilidades e aproximações por meio duma revisão sistemática de literatura. *Revista de Ensino de Ciências e Matemática*, Vol. 8, No. 2, 80–94. http://revistapos.cruzeirodosul.edu.br/index.php/rencima/article/view/1214

Perera, M. and Aboal, D. 2017. *Evaluación del Impacto de la Plataforma Adaptativa de Matemática en los resultados de los aprendizajes.* Montevideo: Centro de Investigaciones Económicas. https://www.ceibal.edu.uy/storage/app/media/documentos/CINVE-Informe_PAM_03102017.pdf

Perifanou, M., Economides, A. A. and Tzafilkou, K. 2021. Teachers' digital skills readiness during COVID-19. *International Journal of Emerging Technologies in Learning*, Vol. 16, No. 8, pp. 238–251. https://online-journals.org/index.php/i-jet/article/view/21011

Piper, B., Oyanga, A., Mejia, J. and Pouzevera, S. 2017. Implementing large-scale instructional technology in Kenya: changing instructional practice and developing accountability in a national education system. *The International Journal of Education and Development Using Information and Communication Technology*, Vol. 13, No. 3, pp. 57–79.

Pooley, J. 2021, July 6. MIT and Harvard have sold higher education's future. *Chronicle of Higher Education*. https://www.chronicle.com/article/mit-and-harvard-have-sold-higher-educations-future?

Postman, N. (1985). *Amusing ourselves to death: public discourse in the age of show business.* Methuen, UK: Viking Penguin.

Potter, C. and Naidoo, G. 2012. Enhancing classroom teaching through interactive radio in South African primary schools: an evaluation of the OLSET programme. *Africa Education Review*, Vol. 9, No. 3, pp. 518–547. https://www.tandfonline.com/doi/abs/10.1080/18146627.2012.742659

President's Committee of Advisors on Science and Technology, Panel on Educational Technology. 1997. *Report to the president on the use of technology to strengthen K-12 education in the United States.* Washington, D.C., President's Committee of Advisors on Science and Technology.

Privacy International. 2018. *A guide for policy engagement on data protection: the keys to data protection.* https://privacyinternational.org/sites/default/files/2018-09/Data%20Protection%20COMPLETE.pdf

Privacy International. 2020, April 24. An open letter to policy makers, data protection authorities, and providers worldwide, regarding rapid technology adoption for educational aims. https://privacyinternational.org/sites/default/files/2020-04/Coalition%20open%20letter%20to%20global%20edTech%20sector%20April%2027%20v5.pdf

Qhobela, M. 2012. Using argumentation as a strategy of promoting talking science in a physics classroom: what are some of the challenges? *US-China Education Review*, Vol. B No. 2, 163–172.

Rashid, T. and Asghar, H. M. 2016, October. Technology use, self-directed learning, student engagement and academic performance: examining the interrelations. *Computers and Human Behavior*, Vol. 63, pp. 604–612. https://www.sciencedirect.com/science/article/abs/pii/S0747563216304204

Ritzhaupt, A. D., Dawson, K. and Cavanaugh, C. 2012. An investigation of factors influencing student use of technology in K-12 classrooms using path analysis. *Journal of Educational Computing Research*, Vol. 46, No. 3, pp. 229–254.

Rogers, E. 1995. *Diffusion of innovations,* 5th ed. New York: Free Press.

Rojano, T. 1996. Developing algebraic aspects of problem solving within a spreadsheet environment. C. K. N. Bednarz (ed.), *Approaches to Algebra: perspectives for research and teaching* pp. 137–145. Dordrecht, NL, Kluwer Academic Publishers.
Russell, M. and Abrams, L. 2004. Instructional uses of computers for writing: how some teachers alter instructional practices in response to state testing. *Teachers College Record*, Vol. 106, No. 6, pp. 1332–1357.
Russell, M. and Plati, T. 2000. *Effects of computer versus paper administrations of a state-mandated writing assessment.* Chestnut Hill, MA: Technology And Assessment Study Collaborative, Centre For The Study Of Testing, Evaluation, and Educational Policy, Boston College. https://www.bc.edu/research/intasc/PDF/ComputerVsPaperStateWriting.pdf
Rwezuva, S., Mutsiwegota, S., Michels, G., Feki, M. and Eun, E. 2021, May 17. Providing a learning solution for millions of in and out of school children in Zimbabwe. *UNICEF*. https://www.unicef.org/zimbabwe/stories/providing-learning-solution-millions-and-out-school-children-zimbabwe
Sangra, A. and Gonzalez-Sanmamed, M. 2010. The role of information and communication technologies in improving teaching and learning processes in primary and secondary schools. *ALT-J: Research in Learning Technology*, Vol. 18, No. 3, pp. 207–220.
Selwyn, N. 1999. Differences in educational computer use: influence of subject cultures. *Curriculum Journal*, Vol. 10, No. 1, pp. 29–48. https://www.tandfonline.com/doi/abs/10.1080/0958517990100104
Shapley, K. 2008. *Evaluation of the Texas technology immersion pilot: outcomes for the third year (2006-07).* Austin, Texas Education Agency. https://tea.texas.gov/sites/default/files/y3_etxtip_quan_0.pdf
Silvernail, D. L. and Buffington, P. J. 2009. *Improving mathematics performance using laptop technology: the importance of professional development for success.* Gorham, ME: Maine Education Policy Research Institute, University of Southern Maine.
Silvernail, D. L. and MLTI Research and Evaluation Team. 2011. *A middle school one-to-one laptop program: the Maine experience.* Portland, University of Southern Maine. https://usm.maine.edu/sites/default/files/cepare/A_Middle_School_One-to-One_Laptop_Program_the_Maine_Experience.pdf
Simonite, T. 2020, August 19. Skewed grading algorithms fuel backlash beyond the classroom. *Wired*. https://www.wired.com/story/an-algorithm-determined-uk-students-grades-chaos-ensued/
Singhal, A., Cody, M. J., Rogers, E. M. and Sabido, M. 2004. *Entertainment-education and social change: history, research and practice*, 1st ed. Mahwah, NJ, Lawrence Erlbaum Associates Inc. Mahwah.
Slavin, R. 1990. IBM's writing to read: is it right for reading? *Phi Delta Kappan,* Vol. 72, No. 3, pp. 214–216. http://www.jstor.org/stable/20404361
Slavin, R. E., Lake, C., Hanley, P. and Thurston, A. 2014. Experimental evaluations of elementary science programs: a best-evidence synthesis. *Journal of Research in Science Teaching*, Vol. 51, pp. 870–901. https://onlinelibrary.wiley.com/doi/abs/10.1002/tea.21139
Sloan Consortium. 2012. *Changing course: ten years of tracking online education in the United States.* Wellesley, MA: Babson College.
Snilstveit, B., Stevenson, J., Phillips, D., Vojtkova, M., Gallagher, E., Schmidt, T., Jobse, H., Geelen, M., Pastorello, M. and Eyers, J. 2015. *Interventions for improving learning outcomes and access to education in low- and middle- income countries: a systematic review.* London, International Initiative for Impact Evaluation (3ie). (3ie Systematic Review 24.)
Somekh, B. 2008. Factors affecting teachers' pedagogical adoption of ICT. J. Voogt and G. Knezek (eds.), *International Handbook of Information Technology in Primary and Secondary Education*, Vol. 20. Boston, Springer.
Spaull, N. and Taylor, S. 2015. Access to what? creating a composite measure of educational quantity and educational quality for 11 African countries. *Comparative Education Review*, Vol. 59, No. 1, pp. 133–165.
Spezia, V. 2010. Does computer use increase educational achievements? student-level evidence from PISA. *OECD Journal: Economic Studies*, Vol. 2010/1, pp. 1–22. https://doi.org/10.1787/eco_studies-2010-5km33scwlvkf
Sprang, A. J. 2011. *Das iPad im unterricht an der KAS: mobiles lernen an der Kaiser Augusta Schule.* https://ipadkas.wordpress.com/
State of Rhode Island Office of Innovation. n.d. Open textbook initiative. *State of Rhode Island Office of Innovation*. https://www.innovate.ri.gov/open-textbooks

Statista. 2021, June . How many cell phones are in the world? *Bank My Cell.* https://www.bankmycell.com/blog/how-many-phones-are-in-the-world
Stockard, J., Wood, T. W., Coughlin, C. and Khoury, C. R. 2018. The effectiveness of direct instruction curricula: a meta-analysis of a half century of research. *Review of Educational Research*, Vol. 88, No. 4, pp. 479–507. doi:10.3102/0034654317751919
Taglang, K. 2020, March 6. Lack of broadband leaves students behind. *Benton Institute for Broadband and Society*. https://www.benton.org/blog/lack-broadband-leaves-students-behind
Tamim, R. M., Bernard, R. M., Borokhovski, E., Abrami, P. C. and Scmid, R. F. 2011. What forty years of research says about the impact of technology on learning: a second order meta-analysis and validation study. *Review of Educational Research*, Vol. 81, No. 1, pp. 4–28.
Tamim, R. M., Borokhovski, E., Pickup, D., Bernard, R. M. and El Saadi, L. 2015. *Tablets for teaching and learning: a systematic review and meta-analysis*. Burnaby, BC, Commonwealth of Learning. http://oasis.col.org/handle/11599/1012
Tamim, S. R. and Grant, M. M. 2013. Definitions and uses: case study of teachers implementing project-based learning. *Interdisciplinary Journal of Problem-Based Learning*, Vol. 7, No. 2, pp. 72–101. https://doi.org/10.7771/1541-5015.1323
Tausin, M. and Stannard, L. 2018. *EdTech for learning in emergencies and displaced settings: A rigorous review and narrative synthesis.* London, Save the Children UK. https://resourcecentre.savethechildren.net/library/edtech-learning-emergencies-and-displaced-settings-rigorous-review-and-narrative-synthesis
Tempelaar, D. T., Rienties, B. and Giesbers, B. 2015. Stability and sensitivity of Learning Analytics based prediction models. M. Helfert, M. T. Restivo, S. Zvacek and J. Uho (eds.), pp. 156–166) *Proceedings of 7th International Conference on Computer Supported Education*. Lisbon, PT, CSEDU.
The DAISY Consortium. 2021. DAISY technologies, projects and services. *The Daisy Consortium*. https://daisy.org/activities/
The Economist. 2021a, May 22. Enemy armies with black mirrors. *The Economist*, p. 44.
The Economist. 2021b, June 5. Bias in, bias out. *The Economist*, p. 77.
The Economist. 2021c, June 26. Post-pandemic education: catching up is hard to do. *The Economist*, pp. 19–21.
The European Consortium of Innovative Universities. 2021, May 20. Flexible European life-long learning pathways: ECIU university's take on the 'European Degree.' *The European Consortium of Innovative Universities*. https://www.eciu.org/
The William and Flora Hewlett Foundation. 2019a, February. *Understanding the global OER landscape.* Menlo Park, CA, The William and Flora Hewlett Foundation. https://hewlett.org/wp-content/uploads/2019/04/Understanding-the-global-OER-landscape.pdf
The William and Flora Hewlett Foundation. 2019b. *The rich global landscape: an overview of the development of open educational resources from 2002 To 2019.* Menlo Park, CA, The William and Flora Hewlett Foundation.
Thukral, H. 2016. Examining the impact of teacher practice on student learning in interactive radio instruction (IRI) classrooms: lessons from New Delhi and Rajasthan (India). Doctoral Dissertation, University of Maryland. https://drum.lib.umd.edu/bitstream/handle/1903/18176/Thukral_umd_0117E_16905.pdf
Tilson, T. 1991. Sustainability in four interactive radio projects: Bolivia, Honduras, Lesotho and Papua New Guinea. M.E. Lockheed, J. Middleton and G. S. Nettleton, (eds.), *Educational Technology: Sustainable and Effective Use.* Washington, D.C., World Bank.
Timmis, S., Broadfoot, P., Sutherland, R. and Oldfield, A. 2015. Rethinking assessment in a digital age: opportunities, challenges and risks. *British Educational Research Journal Early View*, Vol. 42, No. 3, pp. 454–476. https://doi.org/10.1002/berj.3215
Tondeur, J., Valcke, M. and Van Braak, J. 2008. A multidimensional approach to determinants of computer use in primary education: teacher and school characteristics. *Journal of Computer Assisted Learning*, Vol. 24, pp. 494–506. DOI:10.1111/j.1365-2729.2008.00285.x
Tsai, C. C. and Chai, C. S. 2012. The 'third'-order barrier for technology-integration. *Australasian Journal of Educational Technology*, Vol. 28, No. 6, pp. 1057–1060. https://doi.org/10.14742/ajet.810
Twenge, J. M., Haidt, J., Blake, A. B., McAllister, C., Lemon, H. and LeRoy, A. (2021). Worldwide increases in adolescent loneliness. *Journal of Adolescence*. https://www.sciencedirect.com/science/article/pii/S0140197121000853

Ubongo. 2021. Ubongo. https://www.ubongo.org/
UNESCO Institute for Lifelong Learning. 2016, December 16. *Reading for a billion: same language subtitling, India*. https://uil.unesco.org/case-study/effective-practices-database-litbase-0/reading-billion-same-language-subtitling-india
UNESCO International Institute for Educational Planning Learning Portal. 2008. Educational management information system. https://learningportal.iiep.unesco.org/en/glossary/educational-management-information-system-emis
United Nations Department of Economic and Social Affairs. 2021. Sustainable Development Goal 4. United Nations Department of Economic and Social Affairs: https://sdgs.un.org/goals/goal4
United Nations Educational, Scientific and Cultural Organization. 2021. *Open educational resources (OER)*. UNESCO. https://en.unesco.org/themes/building-knowledge-societies/oer
United Nation Educational, Scientific and Cultural Organization. 2020a, March 26. UNESCO rallies international organisations, civil society and private sector partners in a broad coalition to ensure #LearningNeverStops. https://en.unesco.org/news/unesco-rallies-international-organizations-civil-society-and-private-sector-partners-broad
United Nations Educational, Scientific and Cultural Organization and UNESCO Institute for Statistics. 2020b. *World teachers day fact sheet.* http://uis.unesco.org/sites/default/files/documents/world_teachers_day_fact_sheet_2020.pdf
United Nations Educational, Scientific and Cultural Organization. 2020c, April 21. *Startling digital divides in distance learning emerge*. https://en.unesco.org/news/startling-digital-divides-distance-learning-emerge
United Nations Educational, Scientific and Cultural Organization. 2019, November 25. Recommendation on open education resources (OER). http://portal.unesco.org/en/ev.php-URL_ID=49556&URL_DO=DO_TOPIC&URL_SECTION=201.html
United Nations Educational, Scientific and Cultural Organization. (2017). *Second World OER Congress Ljubljana OER Action Plan 2017.* https://en.unesco.org/sites/default/files/ljubljana_oer_action_plan_2017.pdf
United Nations Educational, Scientific and Cultural Organization. 2012. Statistics on radio. http://www.unesco.org/new/en/unesco/events/prizes-and-celebrations/celebrations/international-days/world-radio-day-2012/statistics-on-radio/
United Nations High Commissioner for Refugees. 2018. *Turn the tide: refugee education in crisis.* Geneva, United Nations High Commissioner for Refugees. https://www.unhcr.org/5b852f8e4.pdf
United States Department of Education, Office of Educational Technology. 2010. *Transforming American education: learning powered by technology, national education technology plan 2010.* Washington, D.C., U.S. Department of Education. https://www.ed.gov/sites/default/files/netp2010.pdf
United Nations Department of Economic and Social Affairs. 2006. Convention on the rights of persons with disabilities. United Nations Department of Economic and Social Affairs: https://www.un.org/development/desa/disabilities/convention-on-the-rights-of-persons-with-disabilities.html
United States Department of State. 2021. *2021 trafficking in persons report.* Washington, D.C., United States Department of State. https://www.state.gov/reports/2021-trafficking-in-persons-report/
Université de Genève. n.d. *InZone*. https://www.unige.ch/inzone/
van Dijck, J. and Poell, T. 2018. Social media platforms and education. In A. M. J. Burgess, *The SAGE Handbook of Social Media* (pp. 579-591). SAGE.
van Deursen, A. and van Dijk, J. 2014. The digital divide shifts to differences in usage. *New Media and Society*, Vol. 16, No. 3, pp. 507–526.
Vázquez Toness, B. 2020, May 23. One in five Boston public school children may be virtual dropouts: technical, language challenges keep students from continuing school online. *Boston Globe*. https://www.bostonglobe.com/2020/05/23/metro/more-than-one-five-boston-public-school-children-may-be-virtual-dropouts/
Verbert, K., Duval, E., Klerkx, J., Govaerts, S. and Santos, J. L. 2013. Learning analytics dashboard applications. *American Behavioral Scientist*, Vol. 57, No. 10, pp. 1500–1509.
Vodafone Foundation. 2021. *Instant schools network*. https://www.vodafone.com/vodafone-foundation/focus-areas/instant-network-schools

Wakefield, J. 2021, February 2. *China bans children from using mobile phones at school*. BBC News. https://www.bbc.com/news/technology-55902778
Watkins, A., Tokareva, N. and Turner, M. 2011. *ICTs in education for people with disabilities: review of innovative practice.* UNESCO Institute for Information Technologies in Education: https://unesdoc.unesco.org/ark:/48223/pf0000193655
Watson, G. 2006, January. Technology Professional development: long-term effects on teacher self-efficacy. *Journal of Technology and Teacher Education*, Vol. 14, No. 1, pp. 151–166.
Watson, J. 2019. *The relationship between educational television and mathematics capability in Tanzania.* University of Cambridge.
Web Accessibility Initiative. 2021. *Web content accessibility guidelines overview*. https://www.w3.org/WAI/standards-guidelines/wcag/
Webb, M. and Cox, M. 2004. Review of pedagogy related to information and communications technology. *Technology, Pedagogy, and Education*, Vol. 13, No. 3 pp. 235–286. DOI: 10.1080/14759390400200183
Weston, M. E. and Bain, A. 2010. The end of techno-critique: the naked truth about 1:1 laptop initiatives and educational change. *Journal of Technology, Learning, and Assessment*, Vol. 9, No. 6. http://www.jtla.org
Weston, M. E. and Brooks, D. 2008. Critical constructs as indicators of a shifting paradigm in education: a case study of four technology-rich schools. *Journal of Ethnographic and Qualitative Research in Education*, Vol. 2, No. 4, pp. 81–91.
Wetzler, J. and Bhatt, S. 2021, April 19. Want to make education more innovative? let's invest in R&D. *EdSurge*. https://www.edsurge.com/news/2021-04-19-want-to-make-education-more-innovative-let-s-invest-in-r-d
Wikipedia. n.d. *Augmented reality*. Wikipedia. https://en.wikipedia.org/wiki/Augmented_reality
Wikipedia. n.d. *Copyleft*. Wikipedia. https://en.wikipedia.org/wiki/Copyleft
Williams, N. L. and Harwin, K. L. 2016. One-to-one computing and student achievement in Ohio high schools. *Journal of Research on Technology in Education*, Vol. 48, No. 3, pp. 143–158: DOI: 10.1080/15391523.2016.1175857 (Accessed, March 2019.)
World Bank Group. 2021a. *Online learning models - how to include youth in low bandwidth areas.* Solutions for Youth Employment. https://www.s4ye.org/sites/default/files/2021-04/S4YE%20Brief%20Online%20Learning%20Models%20for%20Low%20Bandwidth%20Areas%20.pdf
World Bank Group. 2021b. *Principles on identification for sustainable development: toward the digital age.* https://id4d.worldbank.org/principles
World Bank Group. 2020. *Cost-effective approaches to improve global learning: what does recent evidence tell us are 'smart buys' for improving learning in low and middle income countries?* https://documents1.worldbank.org/curated/en/719211603835247448/pdf/Cost-Effective-Approaches-to-Improve-Global-Learning-What-Does-Recent-Evidence-Tell-Us-Are-Smart-Buys-for-Improving-Learning-in-Low-and-Middle-Income-Countries.pdf
World Education Forum. 2016. *New vision for education: fostering social and emotional learning through technology.* http://www3.weforum.org/docs/WEF_New_Vision_for_Education.pdf
Wozney, L., Venkatesh , V. and Abrami, P. 2006. Implementing computer technologies: teachers' perceptions and practices. *Journal of Technology and Teacher Education,* Vol. 14, No. 1, pp. 173-207.
Year of Open. n.d. *What are open licenses?* Year of Open. https://www.yearofopen.org/what-are-open-licenses/
York, B. N. and Loeb, S. 2018. *One step at a time: the effects of an early literacy text messaging program for parents of pre-schoolers working paper 20659.* National Bureau of Educational Research. https://www.nber.org/papers/w20659
Zhao, Y., Lei, B., Lai, C. and Tan, H. 2005. What makes a difference? a practical analysis of research on distance education. *Teachers College Record*, Vol. 107, No. 8, pp. 1836–1884. DOI: 10.1111/j.1467-9620.2005.00544.x
Zheng, Z., Bahru, J., Fanyi, X. and Na, K. 2021. A data-driven emotion model for English learners based on machine learning. *International Journal of Emerging Technologies*, Vol. 16, No. 8, pp. 34–46. https://doi.org/10.3991/ijet.v16i08.22127
Zimmerman, B. J. 2011. Motivational sources and outcomes of self-regulated learning and performance. B. J. Zimmerman and D. H. Schunk (eds.), *Handbook of Self-Regulation of Learning and Performance* (pp. 49-64). New York, NY: Routledge