Using technology to facilitate educational attainment: Reviewing the past and looking to the future

Background Paper

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This paper is part of a series of background papers on technological change and inclusive development, bringing together evidence, ideas and research to feed into the commission's thinking. The views and positions expressed in this paper are those of the author and do not represent the commission.

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Introduction

Eighty per cent of the world's children live in developing countries,[1] where high school graduation rates are still very low. About 260 million children are not enrolled in primary school, and overall literacy rates are dismal.[2] Leading education economists described this as: "low-income countries are about 30 years behind middle-income countries, which are about 60 years behind developed countries."[3] Fortunately, there are some correctional forces working to improve education systems. One such force is the rapid adoption of technology. Markets have responded to the education crisis by innovating and producing technology-based teaching and learning aids. A 2017 Forbes report suggested that the global educational technology (ed-tech) industry would grow to be valued at more than US$250 billion by 2020.[4] This report aims to understand how ed-tech impacts on educational attainment, by analysing the issues affecting education and evaluating how ed-tech has dealt with these factors to date.

Section 1 of this paper summarises some of the factors inhibiting educational attainment. Section 2 discusses the factors in more detail and evaluates how technology-based interventions have solved (or have the potential to solve) some of the issues. Section 3 discusses the latest developments in scalable ed-tech and their potential for improving learning outcomes.

A substantial portion of this paper catalogues and critically evaluates the waves of ed-tech interventions. We find that, generally, these have had a beneficial impact on learning across the world. Even though many computer-based interventions are costly at scale, their application has a positive effect on most students' performance.

After-school programmes using computers and mobile devices have been particularly effective in improving learning outcomes. Based on our meta-analysis of existing evidence across the different waves of the education system, we argue for an increase in the use of mobile-phone-based interventions to improve educational outcomes in developing countries. Mobile phone capabilities have proven effective in encouraging positive behavioural change among the stakeholders in education systems, increasing learning outcomes, improving teachers' impact (via distance training and information dissemination) and encouraging greater engagement of relevant actors. Furthermore, they are low cost. Mobile phones and basic connection plans are cheap and have a great reach across markets, whereas computer-based interventions require expansive infrastructural support such as a regular supply of electricity, internet connection and expensive hardware (and maintenance), in addition to support staff. This makes them expensive for remote and economically weaker areas. To increase education attainment in the short term, effort should be applied to maximising the impact of large networks of existing mobile phones, while simultaneously investing in improving the overall infrastructure in developing countries.

Section 1: Factors inhibiting educational attainment

Numerous factors impact on our current education systems. Many are beyond the scope of this paper, but we do highlight some key impediments to quality education for all. These include: poverty, gender, health, early childhood development, and a lack of essential infrastructure – such as electricity or reliable and fast internet connections to support technological interventions, and other basics such as school buildings and toilets.[5,6,7]

Since teachers are integral to education, we also discuss some of the challenges governments face in teacher appointment, training and retention. We explore the interplay of teacher support and identifying learners' needs. Finally, we address the issue of meeting learners' and teachers' needs with limited resources, and the balance of trade-offs needed to achieve this.

Poverty

In developing countries, the average gap in primary school completion rates between the richest and poorest children is more than 30 percentage points. For those in school, the average gap between the chances of the richest and poorest children achieving primary-level skills is 20 percentage points. These figures vary based on gender, location, economy, and conflict. However, large gaps in educational attainment are correlated more strongly to wealth than gender and region.[8] Many families cannot afford school fees[9] and, in many developing countries, even when school fees are subsidised or waived entirely, parents often cannot afford to pay for supplementary costs such as transport, books, uniforms, and so on.[10]

The opportunity cost of sending children to school seems to be very high for low-income families. The International Labour Organization estimates that 152 million children between the ages of 5 and 17 years have to work, leaving them no time for school.[11] When they do attend school, poverty results in reduced school performance. Hence, it is not surprising that socio-economic status continues to be a strong predictor of student success and achievement across regions and age levels.[12]

Gender

Studies of data from 24 low-income countries suggests that, while poverty accounts for the largest difference in educational outcomes, this educational disadvantage is exacerbated by gender, contributing to about 10 percentage points of difference.[13] A UNESCO report reveals that more than 130 million girls around the world are not attending school.[14] In many developing regions, particularly South Asia and Africa, the bias against girls is extremely high.[15] Some of the biggest barriers to female education boil down to cultural norms and institutions, which create economic barriers. A lack of safety from harassment and abuse also results in girls missing out on schooling. For example, researchers highlighted that in Haiti, many girls report experiencing physical and/or sexual violence in or on the way to school.[16]

There seems to be a strong correlation between distances from schools to households and boy-to-girl ratios in such schools, especially in societies where there are frequent reports of violence against women. Researchers have demonstrated that establishing new schools in areas with a low density of existing schools improves enrolment rates and test scores significantly for girls.[17] Therefore, even though there are some concrete solutions to bridging the gender gap in schools, there is still a long way to go before equal access for all genders is achieved, especially in developing regions.

Health

After poverty and gender, health is another large inhibiting factor to educational attainment. Curable and easily treatable diseases such as malaria, schistosomiasis, dengue fever, cholera, diarrhoea and other ailments lead to serious losses of school days in developing countries. Studies have confirmed that good health is associated with positive learning outcomes.[18] In many African countries, one of the major health issues affecting schooling is 'stunting'. The World Health Organization (WHO) describes stunting as impaired growth and development due to "poor nutrition, repeated infection and inadequate psychosocial stimulation".[19] These studies found that, on average, adults who had experienced stunting at 2 years old went on to complete one year less of schooling compared to non-stunted individuals.[20] Research from Brazil, Guatemala, India, the Philippines and many African states finds a strong association between stunting and reduction in schooling.[21] Improving health facilities has significant potential for improving educational attainment.

Infrastructure

Experimental evidence has established beyond doubt that large school construction programmes lead to a significant increase in the average number of years of schooling and future economic returns. It is estimated that the construction of 61,000 schools from 1973 to 1978 by the Indonesian government led to an average increase of 0.12 to 0.19 years of education for each school constructed per 1,000 children, as well as a 1.5 to 2.7% increase in wages.[22] Yet, even today, there is a huge lack of basic infrastructure that results in millions of children staying out of school.[23] Regions with few schools, especially in the sub-Saharan countries, have a high pupil-to-teacher ratio which is not conducive to learning.[24] The absence of schools near households means that children may have to walk long distances to reach schools, if they can get to the schools at all, leading to low enrolment and/or high dropout rates.[25] As discussed above, this 'distance penalty' is higher for girls, with many girls reporting being physically and/or sexually abused on the way to and/or at school.[26]

Many schools in developing countries lack basic elements such as light, ventilation, insulation, furniture, blackboards and laboratories.[27] Lack of drinking water and sanitation facilities keeps learners out of school, particularly adolescent girls.[28] For example, in Chad, only one in seven schools has potable water, while one in four has a toilet.[29] There is also a need to invest in basic educational inputs in countries like Tanzania, where only 3.5% of all Grade 6 pupils had a reading textbook for solo use, while in Cameroon, the textbook-to-student ratio for mathematics books in Grade 2 is 1:13.[30] This reveals the huge gap between the need for and existence of basic education infrastructure and inputs in developing countries in 2018.[i]

Early childhood development

Early childhood is a critical period because it entails the development of vital functions and abilities.[32] The cognitive, social and emotional development of young children plays an essential role in predicting later school outcomes and enrolment in secondary school. Research conducted in Guatemala,[33] South Africa,[34] the Philippines,[35] and Jamaica[36] all found that early childhood development has a long-lasting effect on children's academic and social abilities. Many of these studies emphasised the importance of pre-school and primary school for young children. Current research estimates that more than 99 million children of primary-school age are not attending school.[37] So, it is not surprising that more than 200 million children under 5 years of age are unable to fulfil their developmental potential.[38] Parents in poor households are often not able to spend time with their children, buy them books and toys, or create a stimulating environment at home,[39] which has immediate and long-term effects on the child's continued educational success, choice of occupation and age of first employment.[40]

[i] A World Bank Report titled *Textbooks and School Library Provision in Secondary Education in Sub-Saharan Africa* (2008)[31] looked at the availability of books in 19 African countries and found that in 18 countries there was a seriously short supply for most secondary school students.

Teachers

Teachers are one of the most important stakeholders in the education system. They account for about 30% of the variance in student outcomes.[41] In most education systems, especially in the Global South, teacher salaries constitute the highest recurring expenditure.[42] Yet, evidence suggests that developing countries are unable to attract and retain quality applicants.[43] This is often the result of broken educational management systems and poor state infrastructure, resulting in overwork, burnout and other related issues.

As discussed above, there is also significant overcrowding in schools in remote areas of multiple developing countries. Lack of motivation in teachers in developing countries further complicates the situation.[44] This low motivation has been linked with poor training and working conditions, weak accountability structures and poor growth prospects. While, on average, teachers in developing countries get paid well, a recent study found that 50% of teachers in Lesotho, Zambia, Sierra Leone reported having gone to work hungry.[45] These factors lower teachers' morale, which adversely impacts on student learning outcomes.

Teaching at the right level

As well as looking at the impediments to universal education, we must also acknowledge that there are more children in schools today than ever before. However, despite increasing enrolment rates and many years of schooling, children across developing countries still lack basic literacy skills. In many education systems, students move through their foundation years without having mastered basic literacy and numeracy skills. In 2017, the Annual Status of Education Report (ASER) survey from India reported that less than 50% of all Grade 5 students who were evaluated could read a Grade 2 text.[46] Similar surveys in Pakistan, Kenya, Tanzania, Uganda and Ghana have had similar findings – children perform significantly below competency standards for core subjects.[47] Since traditional schooling systems do not usually have remedial classes, most children who progress through grades without learning basic skills never receive the opportunity to catch up. This also contributes to the high dropout rates observed in developing countries.[48] However, students who are made to repeat grades often still don't receive the support they need, causing them to suffer similar consequences. This is detrimental to society as it leads to a huge waste of resources, and a decrease in confidence in education systems.

Many of the factors impacting on educational attainment need long-term sociopolitical change, along with an infusion of capital. To reduce poverty and improve health outcomes and infrastructure, the state and international donors need to step up their work in the remote areas in developing countries. The ongoing social movement needs constant encouragement to bridge the gender divide. However, in the past two decades, ed-tech has been useful in improving educational outcomes for the marginalised. Section 2 reviews the impact of various technology-based interventions which attempted to address some the factors that often inhibit access to education.

Section 2: Review of existing technology facilitating educational attainment

This section breaks down technology-based education interventions based on those waves of ed-tech that focus on:

1. Access to technology: providing information and communications technology (ICT) tools and hardware to teachers and students

2. Computer-assisted learning (CAL): specially designed software and online courses to improve learning outcomes

3. Teacher training and professional development programmes on effective ICT use

4. Changing the behaviour of key stakeholders in an educational setting.

Analysis of each ed-tech wave is followed by a discussion of the constraints and the policy implications for the wave. In this section, we highlight the 'effect size' observed by researchers in their respective studies. In education research, effect size is often measured by standardised coefficients such as the standard deviation from the mean. Education researchers generally contextualise and compare effects across studies by considering 0.1 standard deviations to be a small effect, 0.3 standard deviations to result in medium effects, and 0.5 standard deviations to signify a large effect, where standard deviation refers to the spread of the data from the mean.[49] However, it is important to keep in mind the context of each study while interpreting their specific effect size.

Access to technology

Access to technology continues to be a major problem in developing countries. For example, only 2% of schools in Malawi have access to computers.[50] There is an urgent need to increase access to technology for the future workforce of such developing countries,[51] in order to:

(a) improve the infrastructure of education systems, leading to better teaching and learning outcomes

(b) reduce the impact of a high pupil-to-teacher ratio via the use of computer-assisted learning (CAL) programmes (see subsection 2. below)

(c) increase equity by reducing the variation in learning outcomes due to variability in teacher quality (see subsection 2 below)

(d) improve communication channels between different stakeholders in the education system.

Before we examine the existing research, it is worth highlighting that the evidence on the topic is patchy. Providing computers or tablets to students, while expensive, did not immediately result in better learning outcomes. This might be because students (and teachers) take time to adjust to learning (and teaching) using a computer. Also, such interventions are complex, and learning gains require that each part of the process flows well, including teaching training. There are promising results from China and India, where interventions were implemented well, and the scope of the impact assessment was narrow. In the subsection below, we summarise some key evidence that has emerged from studies on the topic. We also highlight the need for further studies to test the impact of ICT in increasing collaboration between teachers and making assessment easier in developing countries.

Early evidence of distribution of computing devices to increase access to technology was not very promising. In Peru, researchers conducted a randomised controlled trial, providing 1,000 laptops for home use for children attending primary schools in Lima. The distribution of laptops had no impact on academic achievement or cognitive skills.[52] In Colombia, the private sector donated computers for language teaching in public schools. Evaluation of this programme found little effect on student's test scores across grade levels, subjects, and gender.[53] Researchers in Kenya conducted a randomised experiment to measure the effectiveness of three interventions: (i) providing e-readers for students; (ii) providing tablets for teachers; and (iii) implementing a primary math and reading programme with tablets for instructional supervisors. The study found that ICT equipment did not improve literacy outcomes.[54]

In Turkey, the Ministry of National Education launched the *Fatih* project in 2012. To increase access to quality education, 700,000 teachers and 17 million students were given tablet computers,[55] and the students complained that tablets reduced opportunities for in-class interaction between them and their teachers.[56] These results, while discouraging, do not paint a complete picture of the effects of these programmes on learning. It takes time for students and teachers to gain familiarity with these computing devices. While these evaluations did not show significant positive short-term results, improving access to technology holds great promise for better long-term learning outcomes. They also inform programme design to improve future interventions.

ICT integration that is implemented with a narrower study scope has had more positive effects. In China, researchers evaluated the impact of the 'One Laptop Per Child' programme which involved Grade 3 students in Beijing migrant schools. The study found that this improved students' computer skills and their mathematics scores (0.17 standard deviation).[57] Another study in China conducted a large, clustered randomised controlled trial (6,304 student participants). Some schools' ICT was integrated in the teaching programme; some schools received ICT without having it integrated into their teaching programme; and a third group of schools acted as a control group. The study found that integrating ICT with teaching programmes led to improvement in student test scores (0.08 standard deviation) relative to the control schools. No impact was found in schools where ICT was not integrated in teaching programmes.[58]

In a study of the adoption of tablets and e-textbooks in primary schools in Jordan, 80 students were given pre- and post-tests to measure learning and engagement. The study found that students' assessments improved and were aligned to the core curriculum and increased motivation.[59]

To reduce the cost of ICT interventions, researchers looked at effective alternatives to the expensive but popular one-to-one model. One such case study took place in India where less than 20% of elementary rural schools have a computer.[60] Through public–private partnerships, established to increase access to ed-tech[61] and support teacher training,[62] a non-governmental organisation (NGO) in Karnataka gave away laptops to 800 schools in a 'one laptop per school' programme. Students were given USB drives to save individual work, allowing for some degree of autonomy. A qualitative study of the programme concluded that it had a positive effect for a small cost. The division of time with the computer was a shared responsibility between teachers and students, and the very act of managing limited resources resulted in students displaying judicious behaviour. While the target was to help students improve their English language skills, the initiative also helped students to gain ICT skills. This 'scaffolded'[ii] approach of distributing ICT equipment in a one-to-many method, slowly scaling to increasingly complex technology and training, seems reasonably accessible and could have promising outcomes for many developing countries.

Surprisingly, there have not been many 'access to technology' interventions targeting early childhood development in developing countries – although a study in Kenya and Liberia found that supplying computers and tablets containing age-appropriate content to young children was effective for learning.[63] In developed countries, researchers have also found other benefits of using tablets with young children. These include using touch-screen tablets to measure the development of cognitive and motor skills in early childhood.[64] The results demonstrated that touch-screen tablet technology can provide reliable data on children's performance on scholastic skills rather than via in-person trained assessors which is expensive for the state. Tablets can be used to measure manual coordination, visual attention, spatial intelligence, and so on.[65] This approach also allows for group assessment, reducing the time and resources needed for the tests, and making it a cost-effective option for large-scale distribution of standardised assessments.[66]

Constraints and policy implications

For a long time, improving access to technology has been said to have multiple positive effects on education systems in developing countries. As noted above, in some of the cases, access to technology did improve learning outcomes and potentially led to an increase in equity. However, current evidence does not suggest that access to technology leads to miraculous transformations. ICT integration is a challenging task. In the sections below, we analyse the costs and benefits of improving access to technology. We also provide some policy suggestions for improving access.

In a one-to-one computer distribution model, the upfront costs are very high. And yet, there have been many 'one laptop per learner' programmes implemented to establish that such initiatives are potentially scalable: Uruguay was the first to provide free laptops to all primary school children in the country; Peru distributed about a million computers in poor communities; Kenya and Rwanda together distributed around 600,000 laptops; and India, Thailand and Turkey are distributing millions of tablet computers to children in schools.[67] However, there are several factors that should be taken into consideration:

[ii] 'Scaffolded learning' refers to a variety of techniques used to move students progressively towards more successful learning.

(1) Many regions in underdeveloped countries do not have the basic infrastructure to support the use of computers (due to irregular supply of electricity, and so on.). In Liberia, only 6% of primary and secondary schools have access to electricity.[68]

(2) Studies have found that, in countries such as Zimbabwe, computers were found to be stored away due to the lack of ICT training for teachers.[69]

(3) Integrating ICT (hardware and software) with the regular curriculum is a complex task that requires capacity at various levels which would be very difficult for some countries.[70] As countries such as Cameroon, Comoros, Congo, Guinea, Lesotho and Madagascar currently have no ICT policy and plan,[71] it is not surprising that teachers often develop negative attitudes about ICT integration in their classrooms, aggravated by inadequate training.[72]

(4) Cost is a huge barrier for many parts of the world. Considering the cost of purchasing, setting up and deploying hardware and software - as well as the high costs of running monitoring and evaluation programs in host countries and sometimes remote regions - costs of ed-tech programmes often slowly add up to become prohibitively expensive.[73] To add to this, we must consider the setup costs of supporting infrastructure, such as electricity, internet, maintenance and technical support staff.

(5) In the past, students and teachers have been reluctant to change their routine to integrate technology[74] and view this as an external imposition.[75] From the study conducted in Turkey, researchers learnt that students were also dissatisfied with their learning while using ICT, and even reported physical discomfort (eyestrain and headaches) caused by the use of tablets in classrooms.[76] Teachers also noted other problems, such as students leaving their tablets at home, the tablets needing regular charging, and students being distracted by games on their devices.[77]

Despite these limitations, countries such as China have efficiently integrated computers into the learning environment and have seen an encouraging increase in learning outcomes. The cost of establishing the infrastructure to provide electricity and internet will benefit education and other systems (such as health, transportation, and so on). It is also important to acknowledge that studies looking at the effectiveness of ICT on learning outcomes may miss some indicators of learning that are not immediately evident or that are difficult to measure. For instance, students with e-readers in Ghana were downloading more books.[78] This is an important consideration in regions of the world where books are not easy to access or distribute, where many schools either do not have libraries or have a limited collection of texts (70% of schools in South Africa do not have a library).[79] E-readers or mobile reading devices have the potential to be a more cost-effective solution compared to establishing libraries and related resources in schools at scale. These benefits may not be noticed in short-term reading scores or literacy outcomes, but they may have cumulative effects over an extended period.

The studies discussed above establish that computer ownership alone will not improve educational results. Hence, interventions targeted to improve access to technology should be implemented in moderation, alongside other programmes such as teacher training, curriculum reforms, reducing class size and teaching at the right level (with the use of extra teachers and/or teaching aids). There is also a need to increase awareness about effective use of technology among all stakeholders. Everything from interactive whiteboards and projectors to low-cost tablets and mobile phones has shown some positive results in traditional settings. As mentioned above, it might be worthwhile investing in infrastructure (for example, for electricity) and awareness of ICT. Subsequently, integrating technology in classrooms and providing students and teachers with equipment needs to go hand-in-hand with training in how to use the technology. It might also be desirable to support ICT equipment with specialised content or with a user action plan that allows users to hit the ground running and ensure that learning objectives are met. Finally, considering that cost is a major factor in ICT implementation, projects should always focus on using minimum equipment with an increased user base, as opposed to providing expensive ICT tools to a smaller audience.

Computer-assisted learning (CAL)

In the last two decades, the market for CAL has grown.[80] By 2009, UNESCO had produced a guide for ICT in education, defining CAL as "an interactive learning method in which a computer is used to present instructional material, monitor learning and help in selecting and accessing additional material in accordance with individual learner needs."[81]

With the explosion of the internet, Massive Open Online Courses (MOOCs) are the latest addition to CAL. It has been argued that the adaptive nature of the computer and mobile-based programmes allows students to experience personalised learning. Since its inception, the market has projected it as a tool to address education systems challenges such as:

(1) identifying and teaching at the right level

(2) reducing the negative effects of high pupil–teacher ratios

(3) increasing access to education;

(4) improving learning outcomes.

In this subsection, we discuss the existing evidence on CAL, including online courses and MOOCs.

Unsurprisingly, CAL adoption rates in the Global North are quite high. As a result, there have been many more concerted efforts to understand its impact in developed countries. Over the years, researchers in the US have found CAL to mostly have a positive impact on learning. However, the range of learning has varied considerably. Starting from the evaluation of a software called SimCalc (which integrated an interactive representational technology, a paper curriculum, and a teacher

professional development programme aimed at helping students improve their mathematics skills), the study found that SimCalc led to significant improvements (with student-level effect sizes ranging from 0.63 to 0.56 across experiments) in mathematics learning outcomes.[82] However, another evaluation of the 'I can learn' programme (which delivers instructions on a one-to-one basis and gives classroom management tools to educators) using a test designed to target pre-algebra and algebra skills, found that students who were randomly assigned to computer-aided instruction, on average, scored moderately higher on pre-algebra/algebra tests (0.17 standard deviation).[83]

Appendix 1 lists the modest effects of different CAL evaluations (0.17 to 0.19 standard deviation) on student learning, including the evaluation of Cognitive Tutor Algebra I (CTAI – a tool that provides the entire mathematics course curricula, lesson plans, training for teachers, and so on). This had no effect on student test scores in an algebra proficiency exam in the first year but showed significant positive effects (0.19 standard deviation) in the second year of implementation.[84]

CAL tools to improve reading ability showed similar mixed results. The most promising was a Los Angeles study of a programme called Cell-Ed which distributes English language content by voice and short message service (SMS) on any mobile phone. The programme was designed to help low-literacy and low-skilled US adults improve their literacy and language abilities. Within a period of four months, it significantly increased students' reading scores, equivalent to a two- to four-year increase in reading levels, along with an increase in participants' self-esteem.[85] Success of such low-cost and low-tech intervention highlights lessons for policymakers in developing countries.

Like the results in the Global North, studies in developing countries suggest a range of impacts. In Zambia, a literacy game, GraphoGame (an adaptive mobile word game which gives positive feedback), was tested with elementary school students. It found that students and teachers playing these literacy games together led to improvement (0.12 standard deviation) in students' reading ability.[86] Giving e-readers to children or encouraging the use of mobile-based programmes also showed positive results in Ghana and India. However, the children shared their readers with their extended social circle,[87] and the after-school nature of these intervention was attributed as being the biggest contributor to their impact.[88]

Two other studies from India are worth noting. They looked at CAL's impact on language learning and mathematics:

> (1) In 2002, researchers conducted a randomised study of CAL across 111 schools. In the study, students received instruction on how to use the computers. They then spent two hours per week of shared time working independently with educational software which helped them learn mathematics by using self-paced games in the local language. The researchers found that the use of the CAL aids led to higher mathematics scores, on average, compared to the control group (0.35 standard deviation in first year and 0.47 standard deviation in the second year).[89]

(2) In 2013, another set of researchers conducted a randomised experiment. More than 600 children were recruited, and half were given vouchers to access training centres where they could use the 'Mindspark' programme.[90] This innovative programme uses games, videos and activities to test students' learning levels and provides immediate feedback. The study found that Mindspark increased learning levels across all groups of students, with high learning gains in mathematics (0.36 standard deviation) and their local language, Hindi (0.22 standard deviation), with relatively higher learning gains for academically weaker students.[91]

In India, the CAL exercise took place after school. However, the studies in China implemented CAL during regular school hours and found results that were comparatively modest – improvements in student's standardised mathematics scores of 0.15 standard deviation within a couple of months of the intervention.[92] This effect size was similar to the results found in the US, where the CAL programmes were implemented during school hours.

There are some interesting facts to note across CAL studies. First, apart from the mobile study in India,[93] most programmes showed that students at a higher disadvantage gained more from the programme.[94] Second, in most cases, CAL's impact has been gender neutral.[95] Third, students' growth largely depended on the quality of the instruction that the software provided and the amount of 'scaffolding' in the instructions.[96] Scaffolding is understood as an interaction strategy to help a learner "span a cognitive gap or leap a learning hurdle".[97] One other common factor across CAL programmes was the need for high technical support and additional staff for successful implementation.[98] This adds to the cost of CAL and impacts on the potential for scalability across the world. As discussed above, teacher's knowledge and perception of CAL continues to be integral for its greater success, but teacher training is expensive. This underlines the importance of encouraging more teachers to consider the benefits of technology integration.

Online courses

Online courses do come under the scope of CAL tools, and some of the programmes discussed above were web-based. However, traditionally, online courses have been used by distance learning programmes[99] at institutes of higher education, predominantly in North America.[100] More recently, the success of Khan Academy and similar organisations, such as Byju's in India, indicates the growth of online courses across the K-12 spectrum as well. To add to this, in the past decade, we have seen the emergence of MOOCs, online interactive courses offered by a university or company, usually free of charge. The advantage of online courses is that they can expand access by allowing people to study courses that they would not ordinarily take due to various factors, such as geographical location, age, job status, and so on. These courses also allow people with disabilities to study at their own pace. A recent study on MOOCs, published in *Science*, found that, of 25 million people enrolled in MOOCs between 2012 and 2015, 39% were from developing countries.[101] This led to the popular belief that MOOCs would significantly increase access to education and provide learning opportunities to people in every part of the world.

Closer observation shows that MOOCs are not living up to their promise. First, despite high enrolment, the completion rate for MOOCs is abysmally low (around 5%).[102] One might argue that people may be learning without taking the final test, and so there is inherent value in MOOCs despite the completion rate. However, the evidence undermines this argument. Currently, more than 25% of people enrolled drop out even before the MOOC begins, and close to half the people enrolled do not come back after the first few weeks of the course.[103] Low completion rates also indicate that not being face-to-face in class creates complications with time management. People who fall behind often do not complete the course. Yet, some researchers who studied the impact of online courses concluded that, in the US, MOOCs can increase access to Masters programmes, especially for marginalised communities.[104] Many people who are unable to join higher educational institutions (due to their location, job, etc.), benefit greatly from them. However, studies also find that students attending live classes perform better than those attending online classes at the university level.[105] Similarly, in the post-secondary years, research has shown that students facing the teacher live in a classroom setting outperform students who access courses online.[106] As discussed earlier, ultimately evidence seems to suggest that forms of blended learning where there is a mix of online and face-to-face interaction provides for very conducive environments for learning.[107]

Studies looking at MOOCs from a developing country's perspective concluded that, due to the conditions of access, language, and computer literacy among people in these regions, MOOCs currently are not a viable solution to improve access to education.[108] Researchers note that, while expansion of internet access has led to high enrolment rates from developing countries, such enrolment and completion is mostly limited to the top socio-economic layer of society. Hence, the benefits of MOOCs are not equitable. Even when students from disenfranchised communities enrol in these courses, they complain about feeling unwelcome. Such instances have perceived as social identity threats, when the perceived competence of the group is devalued, (for example, by discarding or not engaging with the online comments of a member of a race and/or gender) while trying to learn, leading to underperformance. Researchers argue that MOOCs, which are predominantly offered in English by Western universities or education providers, need to be more diverse as they currently lead to experiences of stereotyping and social identity threats for people from the Global South. One example of this could be strong moderation of the online discussion boards where MOOC students engage with one another. Diverse courses would ensure that courses are not just tailored (in terms of rhetoric, content and pedagogical ideas) for an audience from the Global North.[109] As in a classroom, the race and accent of the instructors and MOOC participants have an impact on the students, even though such factors are more pronounced in face-to-face interactions. However, if MOOCs are to play the role of a true equaliser, it might be worthwhile reducing social identity threats from platforms that offer such courses. This would arguably increase participation and completion rates and ultimately enhance the impact of online courses.[110]

Constraints and policy implications

CAL aids seem useful and have shown promise across different countries. CAL does manage to level the playing field, by giving all students the chance to learn at their individual level while reducing the impact of a low pupil–teacher ratio. However, to provide these aids to all children, high infrastructure costs need to be considered. Cost and the capacity development of curriculum designers, teachers, teacher training staff, and buy-in from different stakeholders should also be

accounted for. In addition, if access to these aids are provided via a computer laboratory in schools, such schools might have to incur expenditure related to security for expensive devices, along with the cost of repairs and maintenance. A significant cost involved in providing CAL aids to children are the licence fees for use of appropriate learning software. Having these programmes/apps developed/translated to multiple local languages adds to the cost.

Combining these issues results in a significant upfront cost. For example, the Mindspark programme used in India in 2015 cost roughly US$15 per child, per month. While this cost is not unreasonably high, providing access to such programmes at scale would lead to significantly high expenses. Even in the case of MOOCs, which are usually offered for free, there are high costs associated with creating an online course. According to a new study, designing and developing just one hour of an online course could take up to 100 to 160 hours of production time, which may cost somewhere between US8,880 to US$28,640.[111] MOOCs are usually much longer than a single hour.

Interestingly, the jury is still out on the cost-effectiveness of CAL in developing countries. When leading researchers Abhijit Banerjee and Esther Duflo conducted their randomised experiment in India (in 2002–2004), they compared CAL to a remedial tutor programme (where a community worker helps children develop basic skills which they did not master in school). They concluded that the remedial tutor programme was significantly cheaper than the CAL and much more cost-effective. However, researchers in the Mindspark study, after adjusting for price fluctuation, claimed that CAL was more cost-effective than after-school group-based tutoring.[112] This suggests that, with decreases in technology costs, CAL is becoming more cost-effective in regions like India. However, based on the cost of labour, availability of quality teachers, access to computers, and so on, these programmes may still not be easy to implement in some contexts.

Currently, in developing countries, it seems effective to introduce CAL as an after-school programme. Results from many of the studies discussed here suggest that this leads to higher impact. To reduce costs, CAL programmes could be rolled out through mobile devices. Like computers, smartphones can provide adaptive instructions, moulded to the students' learning styles, increasing student motivation and channels of communication between students and educators, at a much lower cost and greater ease of use and implementation.[113] With the cost of internet connectivity falling, mobile devices can also be used to access online courses and MOOCs. Even though MOOCs do not have the benefits of face-to-face classes, (such as enriching and fulfilling conversations and networking opportunities), these courses do offer great flexibility and potential to reach students in remote areas.

If all the infrastructure and cost issues are resolved, it is likely that CAL will have a greater impact in developing countries. In the long run, it promises to be cost-effective in unintended ways. For example, computer and simulation software can help schools and educational centres that cannot afford to set up science labs.[114] As science courses requiring labs need expensive infrastructure and equipment, as well as skilled staff and materials, the comparatively lower cost of setting up digital centres with appropriate software might increase students' access to educational material. More importantly, the computer programmes allow for teaching materials to be adapted, and will resolve the issue of students not being taught at the right level.

Teacher training and professional development programmes

Despite the constantly changing nature of technology, there is currently limited technological pedagogy training for teachers in the developing world.[115] However, tech-innovators have claimed that ICT can be used in teacher training to increase access to quality education and to provide 21st-Century skills such as creativity and critical thinking to young learners.[116] Use of ICT promises to help with: (1) updating teacher content knowledge; (2) updating teacher pedagogical practices; (3) increasing teacher technical knowledge and ability to use ICT tools in class; and (4) reducing the variation in student performance caused by variation in teacher skills. In this subsection, we summarise some of the key evidence from the study of the use of ICT in teacher training across different education systems.

The success of classroom ICT integration and its impact on student learning relies heavily on the quality of teachers' technological pedagogical training. According to UNESCO's ICT Competency Framework for Teachers, in a Tanzanian survey of 206 teachers, ICT competence levels fell by 61% in the beginner category.[117] Teachers who possess a weak understanding of ICT knowledge are not able to effectively use ICT tools.[118] A survey of teachers in sub-Saharan Africa found that teachers perception of effectiveness and barriers to ICT integration was correlated to their technological pedagogical content knowledge and it impacted on their willingness to accept ICT.[119]

A study in Kenya found that some teachers were not using ICT tools for fear of being replaced by technology in the process.[120] This indicates the need for designing teacher training programmes that focus on helping teachers understand the connections between pedagogy, content and the quality of the technology.[121]

In the Philippines, the government's iSchools project gave schools computers, printers, projectors, internet connectivity and training modules to help teachers use the equipment. The initiative resulted in improved teacher ICT literacy and positive learning results for students.[122] In South Africa, installations of interactive whiteboards (IWBs) in the classroom without the training modules did not lead to improvement in student engagement.[123] Clearly, for ICT interventions to be truly effective, there is a need for more targeted professional development for teachers. Such policy[124] may also result in other benefits, such as: teachers generating learning tasks that are multidisciplinary and collaborative;[125] and teachers leveraging ICT for planning, collaborating with other educators, and drawing on resources from databases.[126]

We have discussed the importance of improving teacher's attitudes towards ICT to maximise the positive effect that technology can have on education. In this regard, there seems to be rhetoric that experienced teachers are less likely to learn and use ICT in their teaching. However, evidence does not support this. In a study in Tanzania, the government distributed ICT tools to 2,000 schools and trained their teachers to use them.[127] The study found that the prior education level of the teacher or their teaching experience was not a determinant of their ICT knowledge. However, with greater training and increased ICT experience, teachers' likelihood of using such tools in class increases.[128] This reinforces the need for integrating ICT use and training in teacher training.[129] It should be noted

that studies evaluating the difference in basic ICT skills between pre-service and early in-service teachers have found that pre-service teachers perform marginally better.[130] However, this may be explained by the flexible attitude of pre-service teachers compared to the resistance to change that in-service teachers may demonstrate. While investing in ICT training for pre-service teachers could have more impact, it makes sense to have more ICT training investment for in-service teachers, as they constitute most of the teaching force in most countries.

Researchers have explained the difference in teachers' ICT adoption rates through an analysis of teacher attitudes towards ICT integration. For instance, in Kazakhstan, despite efforts to provide teacher training, (when ICT integration in classrooms and teaching did not reach expected levels), studies found the cause to be teachers' lack of confidence in their abilities to use ICT tools.[131] In such situations, teachers need to be supported in understanding how to use ICT to improve their curriculum, pedagogical practices, as well as to aid with student data tracking. Not surprisingly, studies also show that the more the teachers use ICT tools, the more they find them to be useful.[132] Researchers looked at secondary schools in Rwanda where geographic information systems were introduced, requiring advanced ICT skills. They found that teachers' attitudes depended on their perception of the usability of the technology, which in turn affected adoption rates.[133]

While many teachers in developing countries may not have access to personal laptops, researchers have explored the possibility of teacher training via mobile phones. UNESCO field projects from Nigeria, Pakistan and Senegal found that mobile phones can be effectively used to improve teacher practices.[134] In Nigeria, mobile phones were being used to support the pedagogical practice and content knowledge of primary school teachers. They did this by sending weekly tips on English content and teaching methodologies, along with motivational messages, and information on location-based resources. In Pakistan, mobile phones were used to send training videos and multiple-choice questions to teachers in remote areas to develop their early childhood education professional practice. In Senegal, science and mathematics primary school teachers were sent pre-approved lesson plans. Qualitative studies across these interventions found that a substantial number of teachers reported an improvement in content knowledge and student performance. These interventions also led to an increase in the likelihood of teachers using ICT by 0.76 standard deviation in Nigeria, 0.46 standard deviation in Pakistan and 0.41 standard deviation in Senegal.[135] These studies, consistent with our earlier suggestion, encourage the need to exploit the massive spread of mobile phones in developing countries. Mobile-phone-based, low-cost technological interventions provide a scalable cost-effective solution. Most teachers are familiar with the use of mobile phones, which allows for opportunities of slowly scaling up to more complex technological equipment.

It is important to highlight that most of the studies on teacher ICT efficacy point to the need for extended technical support and continuous training to help teachers practice and expand their repertoire of skills. The implementation of a 10-day teacher training programme for ICT integration in teaching showed no significant change in teacher practices in Tanzania.[136] In contrast, an intervention in Ethiopia had more success. In a two-day training session, teachers took part using ICT for lesson design and received continuous feedback. This was followed by lesson delivery and reflection activities over an extended period of time, which proved more successful.[137] From these examples, it seems that the success of teacher training workshops is highly reliant on sustained and effectively planned activities.

Constraints and policy implications

In a short time, the use of technology in teacher training and professional development programmes has shown very positive results. As noted, it is essential to the success of ICT integration in classrooms. Some of the challenges identified in the implementation of technology-driven teacher training programmes are:

(a) teachers' lack of experience using ICT tools and the resulting fear of technology[138]

(b) teachers' lack of motivation and resistance to change[139]

(c) the lack of proper ICT-based resources and training materials

(d) lack of capacity of teacher training institutes in adopting ICT-based teacher training methods.[140]

The upfront costs of support staff and resources to provide teachers the technical support they need is usually very high. Hence, in the short term, the cost-effectiveness of ICT-based teacher-training programmes can seem unsustainable at large scales for developing countries. However, with the effective use of expansive mobile networks and technology, these costs can be reduced significantly. The return on investment for these programmes is potentially delayed. As teachers slowly become more proficient and collaborative, they will need less support than when starting out. Also, as education systems become more tech-savvy, and teachers become proficient in using the technology, the costs are expected to decrease as the benefits multiply.

Changing the behaviour of key stakeholders in an educational setting

One of the more complex challenges to improving education systems is the fact that various actors often behave in sub-optimal manners. There is a high incidence of student and teacher absenteeism, lack of engagement among stakeholders (such as: low parent–teacher engagement, low parent–student engagement, low overall community engagement with educational institutions, schools/colleges), and low level of information about education in disenfranchised communities at large. Finding ways to encourage different stakeholders to behave in a more optimal manner can have overarching positive effects on the entire education system. This requires a behaviour change where stakeholders are required to plan for the long term, rather than base their decisions on short-term costs and benefits.

Researchers have been evaluating technology-based behavioural interventions for improving education systems. Some of the main interventions that have been rolled out target:

(a) increasing the level of information available to the stakeholders

(b) improving communications between actors

(c) increasing motivation.

In this subsection, we summarise some of the key evidence from the research on behavioural interventions in education. We look at how this research can be leveraged for the benefit of future programme design.

According to classical economic theory, information asymmetry leads to inefficient systems. Hence, it is not surprising to learn that learning outcomes are adversely impacted by lack of information about quality of education and motivation, especially among low-income households. However, now there is an emergence of low-cost innovative ways to use technology to spread information and increase motivation. One such promising intervention using mobile technology was studied by researchers in Minnesota. This intervention evaluated the impact of Text2Learn, a mobile phone texting programme for low-income parents of pre-schoolers, which aimed to promote their engagement in early literacy activities. Under the programme, the researchers sent text messages to parents over a 12-week period regarding information about early childhood literacy, literacy-promoting activities, and opportunities to use early childhood community resources. Participating parents reported an increase in the frequency of engaging in literacy activities with their children.[141] While this is in itself a valuable learning activity, it also has great long-term effects. Traditional evidence on the subject states that children's learning outcomes improve with parental participation.[142] Another study looking at improving information and motivation for education was the evaluation of READY4K!. Similar to Text2Learn, READY4K! sent text messages to parents, containing suggestions of tasks that parents could do to improve their child's preparedness for school, along with words of encouragement and regular reminders. The researchers found that READY4K! increased parental involvement at home (0.22 to 0.34 standard deviation) and school (0.13 to 0.19 standard deviation), which led to pronounced literacy gains (0.21 to 0.34 standard deviation) for children.[143] This effect is also observed in programmes targeting parents with children in higher grades (grade 3 and 4).[144] In California, a study of READY4K! targeted parents of children in kindergarten. Text messages were differentiated and personalised based on the child's developmental level. This study found that differentiated and personalised messages led to children being 50% more likely to read at a higher level compared to the control group. Parents engaged more in literacy activities (by 0.31 standard deviations).[145] Using such technology-based behavioural interventions appears to be a cost-effective way of having a positive influence on early childhood development.

Researchers also found positive impacts when sending information using text messages to parents of children in middle and high school. In a randomised study in California, these parents were provided with detailed, biweekly information about their child's missed assignments and their grades. The researcher found that the intervention lead to 0.19 standard deviation increase in high school grade point average (GPA), a 7.5 percentage point decrease in missing final exam projects, and a 0.21 standard deviation increase for mathematics standardised exam scores.[146]

When a similar study was conducted in West Virginia, the intervention resulted in reduction in course failure by 38%, increase in GPA for both middle and high school students with a 0.10 standard deviation increase on in-class test scores, and an increase in attendance by 17%.[147]

In another study, an online module delivered brief growth-mindset and sense-of-purpose interventions to geographically diverse high school students. It was designed to help students persist when they experienced academic difficulty. Researchers found that the intervention led to an increase in students performing satisfactorily in core courses by 6.4 percentage points.[148] Such effects are also observed in older students who attend college. In an experiment conducted in England, motivational text messages and organisational reminders were sent to students, leading to reductions in the number of students who stopped attending college by 36% and an increase in average attendance by 7%.[149]

Researchers have also tried using mobile phone technology to improve teacher communication with parents and students. In a randomised field experiment, students from Grades 6 and 9 received a phone call and a text/written message every day during a mandatory summer school programme.[150] The study found that this frequent communication increased student engagement, with an increase in homework completion by 40%, and increased class participation by 15%. Among high school students, a school credit recovery intervention delivered weekly one-sentence, individualised messages from teachers to parents. This significantly reduced the percentage of students who failed to earn course credit (by 41%).[151] Based on the evidence, it seems that low-cost interventions greatly reduce dropouts and facilitate better parent–teacher communication to increase parental involvement in children's education. This results in positive impacts on learning outcomes.

Constraints and policy implications

All the above-mentioned behavioural interventions targeted the informational and motivational constraints that led to underperformance. Technology-based behavioural interventions provide additional information that reduces bias and improves student achievement. The advantage of these interventions is that they are very low cost and require very low technology, while any analogous interventions to address the same constraints would be very costly and time-consuming. Hence, they seem scalable in most contexts. However, it should be noted that they are all new programmes, and the long-term effects have not been studied yet. Behavioural science literature states that, in the long run, individuals run high risks of backsliding to their previous state. There is also very little evidence of such interventions in developing countries. However, based on current evidence, education systems in the Global South should explore behavioural interventions that tap into the strength of the vast existing networks of mobile phones to encourage optimal behaviour from different stakeholders and improve learning outcomes. While certain communities/groups still lack access to mobile phone technology (e.g. women in the Global South are less likely to have access to mobile phones compared to men), when compared to other intervention designs, there is still a large scope for exploitation, with reports suggesting that two-thirds of the world population is now connected with mobile devices.[152]

Discussion

The success and effectiveness of the interventions discussed in this section depend on their design, reach, target audience, implementation and cost. As per our analysis, mobile learning interventions seem to be most helpful for poor and marginalised communities. Mobile phones are a low-tech, low-cost method of disseminating educational resources and have been successful across waves of ed-tech in different locations. The most innovative use of mobile phones has been in behavioural interventions that involve students, parents, primary caregivers, teachers (training programmes) and community leaders. Mobile phones allow for the formation of professional learning communities and enable the use of learning apps and software.

CAL tools have also been a great success due to their ability to contextualise these solutions to the needs of the target audience. While most of CAL's success has been in developed countries of the Global North, it has also been beneficial for students from low-income households. Many developing countries are also expanding the use of CAL which has been promising. For this reason, schools are also trying to equip teachers with advanced ICT skills and equipment. Hopefully, with the expansion of basic infrastructure in developing countries, schools in these regions could soon increase the scope and frequency of their integration of advanced ICT equipment in educational environments.

Updating the ICT equipment in developing countries needs to be complemented by equipping teachers with the skills to use these tools. This is both expensive and time-consuming, resulting in a high opportunity cost. In the short term, use of mobile-phone-based interventions for teacher training seems most cost-effective. Mobile teacher training modules can help teachers in developing countries improve their pedagogical and ICT techniques. A greater use of MOOCs and other online courses is also encouraged, covering a wide range of subjects across primary, secondary and tertiary education. However, as they are currently designed, these tools primarily benefit students in developed countries. More MOOCs need to be developed specifically for developing countries to have a greater impact. The same can be said of advanced software, graphing tools, simulations, and others developed for science, technology, engineering and mathematics (STEM) subjects.

Most computer-based interventions have a high implementation cost. This means they are out of reach for many people in the developing world. Computer-assisted learning and access to technology are currently interdependent issues, relying on each other for their success. However, their cumulative cost makes it prohibitively expensive for many parts of the world. Addressing this issue will take time and investment from the international community. Meanwhile, we must continue to leverage the prevailing infrastructure to move forward.

Section 3: New developments in scalable ed-tech

A detailed analysis of the evidence base on ed-tech clearly demonstrates the many benefits of technology-based innovation. Increasingly, improvements in technology are making computers, tablets, and other such devices cheaper, which could reduce the current inequality gap. This could allow us to leverage CAL and adaptive learning which can help teachers and students. For example, Bridge International Academies in Kenya use technology to train teachers and give them scripted lessons using a tablet, which they use while teaching. These scripted lessons include instructional content and classroom activities that ensure a basic minimum quality of classroom instruction for all children.[153] This allows teachers who may not have mastered the curricula to be more effective.[154] Another successful intervention designed by the Bridge academies leveraged technology at scale. It involved using tablets to track teacher absenteeism (teachers log in daily to receive lesson plans) and student progress (teachers regularly input student performance data in the tablets).[155] This provides a two-fold benefit – while reducing teacher absenteeism, schools also have access to detailed student data that allows for the design of more targeted solutions to help struggling students in the classroom. Furthermore, students at the academies use computers during and after school hours for assisted learning. This is a good example of the multifaceted use of existing technology, at a scale that ensures quality education for thousands of children in a developing country. At the same time, the focus on technology has also been criticised, with questions raised about the scripted lesson plans undermining the student–teacher relationship.[156] Therefore, it is important to consider the quality of the ed-tech application in various settings.

In this section, we discuss more new and innovative uses of current technology and promising developments in scalable ed-tech.[157]

MOOCs

A promising new use of existing technology is the increase of MOOCs for teacher training and development of additional skills. Platforms such as TeachScape and Coursera offer various courses for teacher professional development.[158] In the US, many teachers now use Knowledge Delivery Systems (a professional learning platform which provides learning opportunities to teachers and administrators and a platform to engage, share resources, set goals and track progress) courses to access teaching and learning content to improve their effectiveness.[159] Edthena and EdConnective are video platform tools specifically designed for teachers to share their classroom videos to improve learning, allow feedback and encourage mentoring.[160] Adjustments would be needed for such tools to be used by teachers in developing countries.

CAL

CAL has been particularly beneficial for students with disabilities in developed countries. However, due to the high level of poverty in the Global South, many children with disabilities are unable to access these tools. Various small-scale studies by UNICEF and WHO have indicated the huge potential of assistive technology to improve functioning for children with disabilities.[161] Today, there are many software, computer and mobile applications and websites designed and dedicated to helping children with disabilities. ModMath is a mobile app developed to help children with conditions such as dyslexia and dysgraphia acquire mathematics skills.[162] The Braille and Audio Reading Download (BARD) mobile app, created by the US National Library Service for the Blind and Physically Handicapped, provides access to braille and audio books.[163] For children with autism, See. Touch.Learn has developed a visual learning and assessment system.[164] These programmes are designed for specific disabilities that inhibit children's learning, rather than using a one-size-fits-all model. However, there is still a need for these apps to cater to people who speak different regional languages and for those from different cultural backgrounds. Yoza Cellphone Stories, launched in South Africa, is an example of a technology intervention that is culturally competent.[165] Yoza offers an online library of novels and stories written by local authors. The Yoza interactive platform grew in reach without any marketing, taking advantage of students' access to mobile phones. This low-cost technology successfully encouraged teenagers with extremely limited access to quality literature to spend more time reading.

Video games

Innovative use of video games in the STEM fields is also worth noting.[166] GlassLab Games is gaining huge popularity for its engaging interaction with learning content that results in increased learning retention. The UN World Food Programme's educational game Food Force grew to 4 million players in its first year and now has 10 million players around the world.[167] Using these games, CAL programmes are now more interactive and fun than ever, while also acting as a powerful analytical tool to provide targeted feedback to students and teachers. Tools such as Dreambox use machine learning algorithms on collected student data to provide a more adaptive experience.[168] Companies like Knewton and Smart Sparrow allow schools and other education service providers to create and host their own adaptive learning platforms for their students.[169,170] Increased use of such platforms could propel the development of more programmes, tools and apps, using adaptive learning technology.

School management tools

Even though use of technology for school management is not common in developing countries, markets have recently grown for such management tools in the West.[171] Technology-driven management and information systems are now being used in schools to provide decision-makers with the information needed for informed planning, policymaking, and evaluation.[172] Such tools are impacting on leadership, decision-making, human resource management, communication and planning in schools.[173] Gibbon is one such management software which offers multiple features such as tools for finance, staff management, payroll, invoicing and schedules. It also provides teaching tools such as grade books, rubrics, assessments, planner tools, and library catalogues, and allows parents to learn about their child's growth.[174] OpenSIS is another highly regarded school management software package. It is free and offers features such as faculty messaging, government reporting, library management, classroom management, and report cards for parents.[175] The fact that free or affordable school management software is available in the market is highly advantageous for schools everywhere, whether in the developed or developing world. But their adoption is plagued by the same problems that affect ICT adoption by teachers: attitudes of school management, the need for maintenance, lack of appropriate infrastructure, and limited ICT literacy.

Conclusion

Our discussion of the effectiveness of ed-tech has revealed no simple answer to how ed-tech impacts on learning outcomes. The unique problems and constraints of the Global South make it difficult to measure the impact of ed-tech inputs in the system. Education in developing countries faces the challenges of factors such as poverty, gender disparity, low health outcomes, conflict and related political issues, lack of quality infrastructure, and so on. Various interventions have been designed and tested in countries around the world.

Access to technology (for example, e-readers, interactive whiteboards, computers, handheld devices) appears to have had positive effects on learning, contingent on easy and cheap availability of quality multimedia educational resources and proper adoption of ICT. The use of ICT also proves to be cost-effective and more reliable than analogue solutions when it comes to assessment of skills. In the long term, ICT tools will be cost-effective as they provide a viable alternative to expensive science labs and libraries. However, procuring ICT equipment for students and teachers is accompanied by the cost of teachers' training and professional development that is essential to help them leverage the technology in the classroom.

Another hurdle with ICT-infused teacher training programmes is the opportunity cost of time taken away from actual classroom exercises. Many countries have witnessed teachers resisting large-scale introduction of ICT in schools, which calls for stakeholder engagement to ensure success. Yet, there is good reason to believe that proper ICT integration in education systems will have long-term benefits, though there is little evidence currently available. After looking at multiple studies, across waves of technology-based education intervention, we conclude that successful programmes are often the ones that make cost-effective choices of the type of technology used. We believe that using low-cost mobile phones instead of computers, or distributing fewer pieces of equipment per school (as opposed to following the one-to-one model), is advisable for developing countries in the short term. With the gradual improvement in overall infrastructure, these countries should shift towards using more advanced ICT tools in their education delivery system.

On reviewing evidence, we also observed that the positive effects of providing access to technology are often nullified if they are not supported with quality CAL software. In regions where CAL/ICT programmes cannot be properly implemented, it would be more efficient to hire more teachers and reduce the student–teacher ratio in the short term. CAL programmes and software designed to be adaptive to support 'scaffolded' learning appear to have significant positive effects on student learning, once the cost of obtaining the hardware, software and training students to use it is covered. It also appears that the best results come out of use of CAL in after-school programmes. This indicates that some thought should be given to how school time is structured and its impact on learning.

Multimedia content that engages students has resulted in learning gains across fields of study, regional areas and age groups. The impact of these efforts is multiplied if the software solution is contextualised to the learners' region and their needs.

The main barrier for CAL adoption is the cost, since the hardware must be obtained. The process of creating localised software may also become expensive. The effect of online courses on tertiary education has not been as promising – students have complained that online courses do not match up to the quality of face-to-face courses and this reflects in learning outcomes. Often, the design of these programmes is not inclusive enough, and the lack of diversity could negatively affect the learning experience for a global audience. However, low-tech solutions such as text messages to parents about student progress and learning have shown enormous impact on student learning outcomes.

In conclusion, there appear to be tools and resources for almost all needs, but their adoption and effectiveness depend on how well the programme design meets the specific context and needs of the target audience. Various interventions have demonstrated the potential for affordable ICT programmes. And so, we can safely say that, while ed-tech does appear to uphold its promise to deliver results, it must be relied on with caution.

Appendix 1

Citation	Name and description of ICT Programme	Effect size
Roschelle, J., Shechtman, N., Tatar, D., Hegedus, S., Hopkins, B., Empson, S., Knudsen, J., and Gallagher, L. (2010). Integration of technology, curriculum, and professional development for advancing middle school mathematics: Three large-scale studies. *American Educational Research Journal*, 47 (4): 833–878	SimCalc: Integrates an interactive representational technology, paper curriculum, and teacher professional development; aimed at helping students improve their mathematics skills.	Student-level effect sizes ranging from 0.63 to 0.56 across experiments in mathematics learning outcomes.
Roschelle, J., Feng, M., Murphy, R., and Mason, C. (2016). Online mathematics homework increases student achievement. *AERA Open*, 2(4), 2332858416673968	ASSISTments: provides timely feedback and hints to students as they did their homework and the tool gives teachers timely and organised information about students' work.	Improvement in mathematics test score by 0.18 standard deviation, with students who had low prior mathematics test scores benefitting the most.
Pane, J., Griffin, B., McCaffrey, D., and Karam, R. (2014). Effectiveness of Cognitive Tutor Algebra I at scale. *Educational Evaluation and Policy Analysis*, 36(2), 127–144	Cognitive Tutor Algebra I: CTAI – a tool that provides the entire mathematics course curricula, lesson plans, training for teachers, etc.	No effect on student test score on an algebra proficiency exam in the first year but a significant positive effect of 0.19 standard deviation in the second year of implementation.
Barrow, L., Markman, L., and Rouse, C. (2009). Technology's edge: The educational benefits of computer-aided instruction. *American Economic Journal: Economic Policy*, 1(1), 52–74	I can learn: delivers instructions on a one-to-one basis and gives classroom management tools to educators.	Treatment group, on average, scored higher on pre-algebra/algebra tests by 0.17 standard deviation.
Yaghmour, K. S. (2016). Effectiveness of blended teaching strategy on the achievement of third grade students in mathematics. *Journal of Education and Practice*, 7(5), 65-73	Blended learning platform where computerised mathematics instruction and educational material were developed aligned to the curriculum for Grade 3 students.	Test score in mathematics for treated students improved on average by 0.33 standard deviation.

Citation	Name and description of ICT Programme	Effect size
Akgunduz, D., & Akinoglu, O. (2016). The effect of blended learning and social media-supported learning on the students' attitude and self-directed learning skills in science education. *TOJET: The Turkish Online Journal of Educational Technology,* 15(2).	The researchers selected interactive animations and videos, on Systems in Our Body for Grade 7 science and technology lessons, which were shared with students in a virtual classroom, along with carefully prepared homework.	On average, the test scores of treated students increased by 6 points.
Kepceoglu, I. (2016). Teaching a concept with GeoGebra: Periodicity of trigonometric functions. *Educational Research and Reviews,* 11(8), 573-581	GeoGebra: Provides graphical, numerical and algebraic representations of mathematical objects on the same screen.	72% of students in the experimental group gave the correct answer, whereas only 22% of students' answers in the control group are correct.
Banerjee, A., Cole, S., Duflo, E., and Linden, L. (2007). Remedying education: Evidence from two randomized experiments in India, *The Quarterly Journal of Economics,* 122(3), 1235–1264	Children shared a computer for two hours per week (two children shared one computer) – where they played a variety of educational computer games which emphasised basic competencies in the official mathematics curriculum.	Children in the study obtained higher math scores by about 0.35 standard deviation in first year and 0.47 standard deviation in the second year, on average compared to the control group.
Muralidharan, K., Singh, A., and Ganimian, A. (2016). Disrupting education? Experimental evidence on technology-aided instruction in India. *NBER Working Paper* No. 22923	Mindspark: An innovative feature of this software is that it customises the material being delivered to match the level and rate of progress made by each individual student. It analyses the data to identify patterns of student errors, and precisely targets content to help the student improve on these topics.	Treated students showed high learning gains in mathematics of about 0.36 standard deviation and in the local Hindi language of about 0.22 standard deviation and the researchers observed a relatively higher learning gains for academically weaker students.

Citation	Name and description of ICT Programme	Effect size
Rouse, C., and Krueger, A. (2004). Putting computerized instruction to the test: A randomized evaluation of a 'scientifically based' reading Program." *Economics of Education Review*, Special Issue In Honor of Lewis C. Solman, 23(4), 323–38	Fast forWord: language-based audio-visual games that adapt with the child's progress, gradually decreasing modification.	No impact.
Wijekumar, K., Meyer, b., Yu-Chu Lin, P., Johnson, L., Spielvogel, J., Shurmatz, K., Ray, M., and Cook, M. (2014). Multisite randomized controlled trial examining intelligent tutoring of structure strategy for fifth-grade readers. *Journal of Research on Educational Effectiveness,* 7(4), 331–357.	ITSS, a web-based intelligent tutor, gives students strategy along with instructions on how to tackle reading texts.	0.2 to 0.5 standard deviation in student reading comprehension as measured by standardised tests.
Mirzaei, A., Domakani, M. R., & Rahimi, S. (2016). Computerized lexis-based instruction in EFL classrooms: Using multi-purpose LexisBOARD to teach L2 vocabulary. *ReCALL*, 28(1), 22-43	LexisBOARD: A combination of dictionary and a collection of words which provides different meanings of words or concordance lines of words and chunks, based on the context of their use.	Treated students, on average, scored 3 point higher on an English language test.
Jere-Folotiya, J., Chansa-Kabali, T., Munachaka, J., Sampa, F., Yalukanda, C., Westerholm, J., Lyytinen, H. (2014). The effect of using a mobile literacy game to improve literacy levels of grade one students in Zambian schools. *Educational Technology Research and Development* 62 (4), 417–436. http:/dx.doi.org/0.1007/s11423-014-9342-9	GraphoGame: A game for mobile phones with series of levels, which gradually move on to short and increasingly longer words. The game adapts the difficulty level to the child's unique ability level and provides positive feedback to sustain the child's engagement in playing.	Students in the study, on average, score higher on English test by 0.12 standard deviation.
Kam, M., Kumar, A., Jain, S., Mathur, A., Canny, J. (2009). Improving literacy in rural India: Cellphone games in an after-school program. Paper presented at the Third International Conference on Information and Communication Technologies and Development	Cellphones with preloaded English as a Second Language (ESL) learning games were loaned to participants.	The students, on average, gained 3.4 points out of 18 with fairly large variations (-2 to 9 out of 18) and students with better literacy skills gained more from the intervention.

Citation	Name and description of ICT Programme	Effect size
Ksoll, C., Aker, J., Miller, D., Perez, K., and Smalley, S. (2014). Learning without teachers? A randomized experiment of a mobile phone-based adult education program in Los Angeles. *CGD Working Paper* 368. Washington, DC: Center for Global Development	Cell-ED: Mobile phone-based adult education programme in Spanish where the curriculum is provided via a series of voice- and SMS- based operations on the mobile phone.	Programme significantly increased students' basic and broad reading scores, equivalent to a two- to four-year increase in reading levels over a four-month period.

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