Use of Information and Communication Technologies in Education

Effectively integrating technology in under-resourced education systems

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Contents

Executive Summary

Education systems in under-resourced environments face several challenges, some of them exacerbated by the COVID-19 pandemic. A possible way to address some of the challenges is to apply information and communication technologies. However, effectively integrating technology into education systems is a complex task. In this paper, factors contributing to successful integration of technology in education are explored, with a focus on under-resourced contexts. Case studies of successful technology implementation in education systems are discussed and analyzed to identify the factors that drive success. The analysis is framed using the reform strategy offered by The World Development Report 2018 (Learning to Realize Education's Promise). This is expected to provide policymakers and practitioners a way to align their education technology initiatives and strategies with the larger education reform agenda. Key lessons identified from the analysis are as follows. First, it is necessary to articulate *what* precisely does the technology intervention change/enable. Second, it is important to better understand the context to develop technologies and implementation strategies that fit the operating context. Third, it is essential to regularly monitor and evaluate programs and to feed that information into continuously improving design and implementation. Fourth, through the entire cycle of technology implementation, stakeholders must be consulted, understood, and empowered. However small the intervention, realizing the potential of technology tools in education requires keeping in mind the big picture offered by these lessons.

1. Introduction

Investments to introduce various forms of information and communication technologies (ICTs) in public school education systems around the world rapidly increased over the last two decades and witnessed significant expansion during the COVID-19 pandemic. The classification and magnitude of such investments vary based on what report one chooses to read. Nonetheless, most of these investments have attempted to reproduce hardware-centric educational technology projects that were conceived in, and hence better suited to, resource-rich environments. The evidence on their effectiveness is either limited or largely mixed. What will it take to succeed, then, when thinking about ICTs in education for the long run?

2. Technology for *what*?

> *"If I were given one hour to save the planet, I would spend 59 minutes defining the problem and one minute resolving it."*
>
> – Anonymous

Challenging the status quo of school systems is hard. Ideas to re-imagine the system, many involving the use of ICTs, have been proposed over decades. In 1913, Thomas Edison, an American inventor, predicted that books would become obsolete in schools and be replaced by motion pictures. Around the same time, Edward Thorndike, a Columbia University educational psychology professor, imagined 'adaptive textbooks' that would change based on individual students' achievements. Sidney Pressey, an Ohio State University professor in 1933, and later B.F. Skinner, a Harvard University psychology professor in the 1950s, posited and even modeled teaching machines. In 1972, computer scientist Alan Kay conceived the Dynabook, "A Personal Computer for Children of All Ages" as yet another idea of personalized learning using what we today know as tablet computers. A lot of these ideas came from the Western world, especially the United States, and constitute the rich and fascinating history of envisioning ICT use in education systems.

It is pertinent, therefore, to highlight that 'technology innovations' have been a key factor in shaping education systems around the world. The fundamental approach to solving realworld problems using technology requires sufficient rigor in defining the problem from an end-user perspective, articulating why it's important, developing ideas and re-imagined processes that *may* be enabled or expanded/scaled with the use of technology tools, and ensuring that the end-users are part of the solutioning exercise. The ideas of Edison, Pressey, and Skinner highlighted in the previous paragraph perhaps reflected increasing demand for education as the problem and 'mechanization' as a way of improving efficiency in an ever-expanding classroom. The ideas of Thorndike and Kay probably identified how-to-teach-at-the-right-level and how to encourage individual exploration as the problem and offered 'personalization tools' as a solution.

Before envisioning an ICT-enabled model for addressing the problems facing school education today, it is worthwhile pausing and reflecting on *what* we are solving for in today's regional context. Several regions around the world are faced with challenges of access, quality, and inclusion in education. In response, the World Development Report (WDR) 2018 proposed a reform agenda with three complimentary strategies to realize education's promise. This paper attempts to articulate key problems that need to be solved in executing the three strategic areas of the WDR reform agenda, and how ICT can address some of those.

3. Technology as a potent tool to address challenges in under-resourced environments

The World Development Report 2018's proposed reform strategy involves the following:

- assessing learning to understand the current state of the system as well as set direction for the reform agenda,
- acting on evidence to resolve barriers to learning, and
- aligning all actors to make the whole system work for learning.

3.1. Assessing Learning

In the past decade and a half, assessments have been central to the discourse on education reform around the world and have been responsible for bringing into public consciousness the issue of low levels of learning in most national education systems. A

2012 World Bank report[3] highlighted three main drivers of the quality of information produced by an assessment system: the enabling context, system alignment, and assessment quality. Broadly speaking, the enabling context covers policies, resources, and implementation arrangements for assessment activities; system alignment covers the connection between assessments and other components of the education system such as learning goals, standards, curriculum, and teacher training; and assessment quality covers the psychometric quality of the instruments, processes, and procedures used for assessment. Analyzing a country's assessment systems using such criteria offers interesting insights into specific problems/areas that need to be addressed/strengthened and *if* or *how* ICT tools might help. For instance, several countries grapple with issues of widespread cheating in high-stakes examinations. In other cases, there are issues with the alignment of national large-scale assessments to the constructs/content they were intended to measure, i.e., the curriculum or learning standards. Test-items/questions and procedures may also vary in quality across regions and years, making the results difficult to compare. The process of administering assessments and collecting and collating data may also be prone to errors at various stages, resulting in unreliable data, time-consuming analysis, and a slow and ineffective assessment-to-action loop.

Some of the efforts to improve assessment systems have used ICT tools to improve the fidelity of the data, including integration of portable devices like mobile phones and tablets into data collection procedures, and using downstream analytical tools to shorten the assessment-to-action cycle. One example of interventions that have targeted system-wide changes is the 'big-bang' assessment reform in the country of Georgia in 2010, wherein all school graduation examinations moved to computer-adaptive testing (CAT), a type of testing that adapts to the ability level of the person taking the test.[4] There are several potential benefits of such a shift, ranging from a reduction in cheating (because test takers are shown different questions) and availability of more precise ability-estimates of candidates, to development of extensive item banks well-aligned with national standards that can lead to more reliable and comparable results over years. An evaluation by the Georgian Ministry of Education and Science concluded that the computer-adaptive testing in Georgia was more cost-effective compared to administration of the same tests using paper and pencil techniques, and that its introduction had met the goals of launching an efficient, fair, and objective approach to student assessment.

[3] (Clarke, 2012)
[4] (Bakker, 2014)

The success of this model in Georgia, however, owes much to a number of enabling factors specific to the 'context'. The small size of Georgia, and the presence of a well-developed internet infrastructure in its schools served as key ingredients to think in the direction of technologically advanced assessment delivery modes. A strong commitment from the government to introduce national tests, fund the recurrent costs, and guarantee continuity of operations underpinned the enabling context. The most important success factor, however, was the leadership of a highly competent and experienced testing institution (National Assessment and Examinations Center, NAEC), and its ability to bring schools on-board. NAEC developed the CAT tool using its existing staff, with some training by international consultants in areas such as item calibration and test analysis using software packages. NAEC then conducted extensive outreach campaigns – led by its Director, a well-respected and trusted public figure – by visiting all regions and meeting with representatives of virtually all schools involved. The meetings focused on sharing information about registration and score dissemination processes, demonstrating working prototypes of the test delivery system and test items, and, most importantly, convincing schools that the tests would not be used against them and that the outcomes would not be disastrous as many feared. This was complemented by visits of technology specialists to each school for inspection of computers and connectivity. This spurt of activity was followed up with sharing of information about the test with the public and media, setting up of a dedicated Frequently Asked Questions section on the website and social media channels, an open-door policy of interaction with the media, and launching of a web-based practice test. It is worth stressing that while decisions around the 'right technology' were important, overall success was rooted in a much more comprehensive analysis of needs and goals, and a rigorous implementation and stakeholder consultation process. In fact, the role of the NAEC in successful implementation cannot be overstated; although, it was politically not responsible for the decision of administering computer-adaptive testing, it took on the onus of engaging the ecosystem through outreach, ensuring stakeholder buy-in and successful implementation.

Another example of efforts to improve national assessment systems is Afghanistan's Monitoring Standards in Educational Growth (MTEG) program, launched in 2013, which is designed to assess the learning progression and trends in achievement outcomes of students at key stages of schooling (Classes 3, 6 and 9).[5] The program has developed a computer-based assessment for its Class 3 assessments[6].

3.2. Resolving Barriers to Learning

While assessments tell where one currently is and how far one has moved, this information is only helpful when acted upon. Drawing from an ever-growing body of evidence on what works, the World Development Report 2018 highlighted four key school-level ingredients for learning: prepared learners, effective teaching, learning focused inputs, and the skilled management and governance that pulls them all together.

3.2.1. Prepared Learners

The World Bank has laid out a three-pronged strategy to accelerate progress towards the goal of ensuring all children have the opportunity to reach their full potential[7]: establishing an enabling environment; ensuring that the portfolio of programs covers healthcare, nutrition, child protection, social protection and early learning; and, monitoring and assuring quality through compliance with quality standards and data availability. Similar to the case of assessments in the previous section, using such a framework in analyzing a country's Early Childhood Development (ECD) system ensures the primacy of the needs and aspirations of all stakeholders in designing and delivering solutions, surfaces gaps, and thereby, generates insights on *whether* and *ways in which* ICT can play a role in solving the identified challenges.

For example, wide range of Government departments delivering similar services due to a lack of inter-sectoral coordination mechanisms for designing, delivering and monitoring services and outcomes may become constraints to an enabling environment. Lack of quality assurance mechanisms may lead to proliferation of poor-quality curriculum and learning resources, untrained professionals, and ill-equipped child-care centres that adversely affect children's growth and learning.

[5] (ACER Centre for Global Education Monitoring, 2016)
[6] See Box 1 for a detailed description
[7] (Neuman & Devercelli, 2013)

Use of technology can sometimes provide governments simpler ways to deliver quality ECD interventions at scale. For example, one of the most inexpensive and widely available technologies, the radio, has been used to deliver interactive radio instruction (IRI) targeting the most vulnerable children in remote communities, with very encouraging results. IRI is a distance education system that combines radio broadcasts with active learning to improve educational quality and teaching practices. The first phase of *Radio Instruction to Strengthen Education* (RISE) project in Zanzibar used IRI to deliver songs, stories and physical activities to a group of underserved young children (preschool to Grade 2) and a lightly-trained adult facilitator in Zanzibar's two lowest-performing districts. The project was led by Zanzibar's Ministry of Education and Vocational Training (MoEVT). MoEVT started with empowering educators through capacity building of its educators in developing interactive audio programs and accompanying instructional and learning materials, producing audio and video programs, and conducting monitoring and evaluation activities. These educators could then integrate math, life skills, and English and Kiswahili literacy lessons into comprehensive 30-minute programs. The programs complemented the standard curriculum, engaged listeners through locally based stories and activities, and could support teachers with minimal ECD instructional experience. Early childhood learning centers (*TuTu Centers*) were then established in areas with poor access to ECD and education, and RISE staff trained local community members as mentors to guide learners through the *TuTu* broadcasts and post-broadcast activities in non-formal settings identified by the community. MoEVT also trained its district officials in IRI implementation, in addition to monitoring and evaluation. The programs were broadcast on the government-sponsored radio station as well as through portable media player technology. The initiative delivered deep impact, exhibited through significant test score gains across all three tested subjects (Kiswahili, Math and English)[8,9].

The success of the project once again highlights that the 'right technology' is the one that suits the context; in this case the one that can reach vulnerable children in remote areas and is easy to use. It also brings to fore another critical element for successful technology-driven interventions: robust change management and empowerment of the last-mile actors. Capacity building at various levels and engagement with the communities not only enabled alignment for easy delivery of the project, but also aided the MoEVT's ability to take over implementation and institutionalize it in just a few years.

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[8] (World Bank Group, 2017)
[9] (EDC, 2015)

Other noteworthy models of technology use in ECD are Storyweaver (India) and Ready4K! (USA). Storyweaver (India) is an online platform that gives children and adult-caregivers opportunities to read, print and even discuss levelled stories written in multiple languages, and also allows illustrators, authors and translators to collaborate to create and translate stories.

Ready4K![10], an initiative that was implemented in the San Francisco Unified School District during 2013-14 and 2015-16, aimed to address the large variations in learning experiences for young children with varying family backgrounds. One study had found that by the age of four, children in "welfare families" hear about 3 million fewer words than children in "professional families". Ready4K! intended to bridge this gap by supporting parents of young children to provide a rich home-based learning experience. However, most existing parenting based interventions suffered from challenges of low access, high cost and parent dropouts, and therefore, had shown very little success. Given this context, Ready4K! arrived at a smart design through a careful consideration of the context and factors that affect implementation of parental support programs. Firstly, it employed a widely available and inexpensive technology, i.e. of text messages, as the primary mode of delivery of the intervention. This ensured that the project reached *all* communities, including the under-resourced Black and Hispanic communities which had the highest drop-out rates from parenting programs. Secondly, Ready4K! broke down the complexity of parental support into an accessible package of three messages a week – one message with a simple bite-sized step for the parents to follow, along with two messages for encouragement and reinforcement. The program resulted in increased parental involvement at home and school, leading to gains in early literacy. This initiative exhibits the promise of small bits of information, and widely available, low-cost and scalable technology solutions in changing entrenched and complex adult behaviors, echoing the importance of understanding the context and identifying the right technology for that context.

Similar to other challenges in the education systems, technology may not be *the* answer to the challenges of ECD. However, some right approaches that can complement and enable activities related to ECD are possible, provided a clear understanding of the context in which ICT tools can help.

[10] (York, Loeb, & Doss, 2017)

3.2.2. *Learning Focused Inputs and Effective Teaching*

While a major part of the strategy to prepare learners entails focus on early childhood care and education, the strategy includes directing attention to the value of increasing motivation and effort in school and the need for increased and improved opportunities to learn at home. There is a plethora of solutions that seek to provide rich and engaging lessons, activities, resources and support for both the classroom and home, mostly on literacy and numeracy curricula for primary grades and above. They range from tools that aid reading at home to those that enable sharper learning experiences in school. Some of these tools may be more resource-intensive than others, but there are many that make use of existing and easily accessible technologies.

Available in India and Pakistan, Worldreader is a widely-available tool that allows children and adults to read stories from mobile devices, thereby increasing the exposure to quality content and support outside the classroom. There have been pilots in Pakistan that use SMS technology to deploy short daily assessments. Solutions using SMS and Interactive Radio Instruction (IRI) demonstrate the potential of well-designed technology-based tools to deliver improved learning experiences both in and out of classrooms, particularly in low-cost and limited-mobility environments. Another example is that of Mindspark, a mathematics learning program that uses adaptive-learning technology. A study in India[11] found that students who used Mindspark after-school for 4.5 months, showed gains that were greater than those observed in almost any evaluation of education interventions in poor countries.

Technology can also be used to support teachers in improving their instruction. In Uganda, UNICEF's MobiStation – referred to as a digital 'school in a box' – is equipped to facilitate a richer learning experience in both formal classroom and informal communal settings. It does so through a combination of laptop, speaker, and projector rolled into one portable suitcase. While hardware-assisted systems and software preloaded with content constitute most technology-enabled tools, there are a few examples that go beyond to set up virtual or physical platforms that support content creation, dissemination and consumption. The Digital Infrastructure for School Education (DIKSHA) platform in India is one of such platforms. It is an open learning platform with a collection of learning resources in literacy

[11] (Muralidharan, Singh, & Ganimian, 2016)

and numeracy. The platform allows for creation and publishing of interactive teaching content for learners. The created stories, assessments, worksheets, simulations, games and activities can be accessed through a website and mobile app. All the education content developed on it is linked to a particular curriculum, and can be used by students, parents, schools and tutors. The platform provides analytics and dashboards that help track ratings, engagement and learning levels of users. With availability in 12 languages and enablement of content creation by teachers, parents and content creators, it represents a step towards democratization of content creation and rating.

ICTs and properly developed multimedia materials can also enhance the initial preparation of teachers by providing good training materials, facilitating simulations, capturing and analyzing practice-teaching, bringing world experience into the training institution, and training potential teachers in the use of technologies for teaching/learning. For example, teachers in the Indian state of Karnataka convene under the umbrella of the Subject Teacher Forum (STF) to engage in discussions related to their subject on online communities and create and share open digital educational content. All of these are tools that were built for the context, address both content and infrastructure issues, use locally aligned or created content, and have a component of training teachers in using them well.

3.2.3. Skilled Management and Governance

At the school/institution level, technologies are crucial in such areas as admissions, student tracking, personnel management, staff development, and facilities management. At the system-wide level, technologies provide critical support in domains such as school mapping, automated personnel and payroll systems, management information systems, communications, and information gathering, analysis, and use.

ICT can be valuable in storing and analyzing data on education indicators, student assessment, educational infrastructure (physical and human), cost, and finance. More importantly, they can assist in constructing and assessing policy scenarios around different intended policy options to determine requirements and consequences and to help select those that are the most appropriate. An example of use of ICT for management and governance may be found in the Indian state of Karnataka. It is an example that is equally important for the manner of its implementation, as it is for its scale and sustainability.

Karnataka has over 60,000 schools (almost three-fourth of them managed by the government) and more than 450,000 teachers (with more than 50 percent of them employed in government schools). Through the 1950s to early-1990s, Karnataka's teacher recruitment and transfer processes were largely decentralized, ad-hoc and dominated by patronage networks. District and state level bodies, comprising local members of the legislative assembly and other influential political leaders, conducted the recruitment of primary and secondary school teachers. Teacher transfers were also largely undertaken as a means of punishing errant teachers and rewarding those with connections. Susceptible to corruption, the existing systems and practices invited widespread criticism and dissatisfaction from teachers[12]. Given this context, the Government of Karnataka made a series of key reforms in improving the teacher recruitment and transfer systems. Amongst all the changes made, centralization of teacher recruitment and transfer processes within the office of the Commissioner of Public Instruction (CPI) in Bangalore and laying out of transparent criteria for teacher selection and transfer were the two most important ones. Once the problem was well defined and solutions envisioned, technology played a crucial role in the actual implementation. The sheer scale of the implementation entailed a large volume of administrative tasks, and this was facilitated through an iterative installation of technology-enabled systems and processes, often adapted from other sectors of education where they had already met with some success. As these rules and processes were continuously improved and several new acts were enacted in recognition of success of executive orders, the technology systems were also revamped, ensuring sustained use over time. Thus, clarity in problem and solution definition, evidence-based and iterative manner of implementation, and support from leadership were key to the success of using technology in reforming teacher recruitment and transfers at scale and in making the processes and systems more transparent, objective and fair.

Similar to the system in Karnataka, the Sindh School Monitoring System (SSMS) in Pakistan is also an example of an expansive system-wide technology system that was created to improve governance, accountability and service delivery. It constitutes field based monitors who use smart phones and biometric devices to monitor schools on a regular basis on a variety of attributes such as school status, infrastructure, facilities, staff and student attendance, which are then transmitted in real-time to centralized dashboards in the Education and Literacy Departments and Directorate of Monitoring & Evaluation. This helps planning and informs decision-making by the Sindh Government through review meetings

[12] (Ramachandran, et al., 2018)

at the district level. With an iterative design that has resulted in the system spanning 29 districts, monitoring of more than 26,200 schools, and biometric verification of 210,000 education staff, this system has helped the Government identify and take action against 40,000 absentees and 6,000 absconders. This project, too, benefited from a detailed analysis of the existing condition of the public education system in Sindh, along with an enabling environment that was provided by the reform agenda of Sindh Government's education sector plan, rather than being a standalone initiative.

Box 1: Showcase Stories from South Asia

<u>Monitoring Trends in Educational Growth (MTEG), Afghanistan</u>

The Monitoring Trends in Educational Growth (MTEG) Program was launched in 2013 by the Learning Assessment Unit of the Afghanistan Ministry of Education, in partnership with the Centre for Global Monitoring at the Australian Council for Educational Research (ACER-GEM). Operational till 2017, MTEG was conceptualized with the purpose of providing policy makers with information about the state of education outcomes in Afghanistan. It aimed to do so by measuring trends in achievement outcomes in single classes over time (e.g. Grade 3, year-on-year), and growth of achievement in cohorts throughout the school cycle (Grades 3, 6 & 9)[13]. MTEG also provided information about the contextual factors around teaching, learning and home environments in order to provide a more complete picture of the influences on learning outcomes[14].

Based on the results of the Grade 6 assessments that were conducted in 2013, the ACER team managing the program anticipated that students in Grade 3 would be spread across the spectrum of reading literacy, with significant numbers at very basic proficiency levels. To ensure accurate measurements for all children in Grade 3, including those with very basic levels of proficiency, the team arrived at a few innovations.

Firstly, students were sorted into two groups, *Emerging* and *Independent Readers*, based on a short preliminary reading assessment that was conducted by the test facilitator. These two groups were directed to two different assessments, with the *Independent Readers* being

[13] (ACER Centre for Global Education Monitoring, 2016)

[14] For further information about MTEG in Afghanistan see https://www.acer.org/gem/key-areas/system-strengthening/mteg. The Grade 3 MTEG report is forthcoming.

assigned a slightly more challenging test than the *Emerging Readers*. However, to accurately measure different levels even within these broad groups, both the assessments had items of a range of difficulty levels.

Secondly, the Grade 3 assessments were conducted on tablets that allowed for interactive input methods. The questions used touch-enabled responses such as *Hot spot, multiple choice and drag-and-drop* question types. The assessments also used integrated audio files for many of the questions, including for those assessing letter sounds, word recognition and listening comprehension. An important reason for students being read-aloud questions was that it allowed for more accurate testing of phonemic awareness, phonics, vocabulary, listening comprehension, and mathematical abilities of students who were not strong readers. Use of colourful interfaces, playful design and interactive input methods motivated students to participate in these assessments. Another very important advantage of conducting assessments on tablets was that a consistent assessment experience was provided to all students. The students also enjoyed the added support of accessing audio prompts as many times as they needed without the hesitation of requesting repeated clarifications from a human facilitator. Before the assessment commenced, each participant required around 15-20 min to acclimatize herself/himself with the software through guided walk-throughs of the interface and practice questions. The ACER team claimed that this resulted in almost all students being able to take the test without any challenges. The tablet-based assessment was available for offline delivery, meaning that no internet connection was necessary while students completed the assessment.

Along with the benefits indicated above, the use of technology to deploy these assessments resulted in greater efficiencies. Data-collection on a tablet meant that the data was securely transferred to ACER's servers as soon as the tablets were connected to the internet, thereby reducing the fear of loss of data. Encryption and user passwords ensured that both assessments and test data would be secure even in the event of loss of tablets. Technology-enabled implementation also resulted in an ability to complete assessments in a short period of time. Using this innovative approach to assessments had numerous benefits, including enhancing the efficiency and effectiveness of data collection in the MTEG program. This use of technology supports the collection of high quality and reliable data that can be used to inform policy makers about the learning outcomes of Grade 3 students in Afghanistan.

Mindspark, India[15]

Educational Initiatives (EI), the firm that designed the Mindspark software, had been founded on the idea that educational change could and would be catalyzed by demonstrating gaps in students' learning. Consequently, EI had been conducting assessments and educational research, and had assessed about 14 million students since their founding in 2001. However, the slow pace of change in the education sector, despite EI's efforts in highlighting and explaining problems through its assessments, along with having unraveled patterns in the misconceptions and challenges that children experience, inspired EI to look beyond assessments. In 2008, the firm started developing Mindspark, a computer-assisted learning (CAL) software that enables students to learn mathematics and language at their own level and pace, and is meant to supplement classroom instruction.

A mathematics-only program was launched in 2009, which is aligned to the requirements of a range of state and international curriculum, and currently packs content for Grades 1 to 10. In 2016, an English reading and language program for Grades 4 to 9 was also introduced. The roll-out of the Mindspark program has been staggered over device-types, starting off with a desktop/laptop version in 2009, a tablet version in 2010, followed by the release of a device-agnostic version in 2013 that required only an internet browser. Finally, in 2014, EI launched an offline version of Mindspark that would need only periodic internet connections, learning from the various cycles of its implementation.

Consciously staying away from hardware innovations of digitized whiteboards and textbooks, the Mindspark system chose to aim for a cloud-based student-centric software, wherein the focus is on 'absorption' of learning rather than the simple delivery of curriculum. This is enabled through a multitude of features, such as the use of finely-graded questions, adaptive logic, and intelligent responses and modules. These ensure that students are on a very gradual learning trajectory, are directed to different questions based on whether their responses are correct or not, and are provided continuous feedback, remedial instruction and quizzes. To support students with a range of abilities in comprehension, it can provide voiceover support in mathematics, and has built-in graphics, animations and educational games for an extensive part of the content. Additionally, it implements a smart recognition system that not only rewards good performance, but also

[15] (Muralidharan, Singh, & Ganimian, 2016)

encourages desirable behaviors such as persistence in completing topics, spending time to read through feedback, and consistent use of the software. While these features drive student engagement with learning, the system also integrates a feedback system that allows students to rate each question (Like/ Dislike/ Excited/ Bored/ Confused) as well as provide typed feedback to EI.

In an illustration of good design, Mindspark implementation begins with a needs-assessment, infrastructure check, analyses, followed by dialogue among EI, teachers and Principal to arrive at a decision on the suitability of Mindspark for the present challenges and circumstances. Only once Mindspark is found suitable, does the team begin implementation either in a few classrooms as a pilot or throughout the school, and provide teachers and students with orientation and training to use the software. Further, the program gives significant control to individual teachers, i.e. teachers can 'activate' content based on what they have taught in the classroom, and then, inform their instruction using reports generated by the program. Over the years, the program has been tried and tested in a variety of contexts, starting from private schools to public schools in the Indian states of Madhya Pradesh, Gujarat and Rajasthan. In 2012, recognizing the need and potential for innovation in urban centres, the Mindspark program was implemented in after-school learning centres in the urban slums of Delhi. The implementation in Delhi has been rigorously tested by researchers associated with MIT's J-PAL.

The study found that students who used the Mindspark program showed significant gains compared to the control group. In addition, the evaluation also found great relative gains in the levels of *academically-weaker* students compared to the control, since the rate of learning in the control group was minimal. While the study did not experimentally isolate the effects of the CAL system from the effects of group teaching and additional instructional time, it presents evidence that indicates that the most significant contribution was from the software. The software's abilities to instruct at the appropriate level and continually update the content for individual students based on their individual learning trajectories were found to be the primary drivers of success.

On the matter of productivity, too, the research presents encouraging results. Estimates in the study suggest that, at a scale of 1,000 schools, (steady-state) implementation of the program would increase the government's annual per-child cost by less than 2%. In fact, even with high fixed costs, absence of economies of scale and low attendance, the program delivered greater learning at lower costs than public spending. In the context of substantial percentages of children in the South Asia region severely lagging their levels, the study provides findings that could have remarkable implications. Using estimates, it hypothesizes that gains in learning levels by using the system regularly could lead to students catching up with their appropriate grade-level standards.

The study also presents some very compelling social and policy benefits of effectively implementing a system such as this. Complete personalization offered by a CAL system allows for children to learn at their own pace, which doesn't only mean that it can deliver content at a lower level and/or pace; it can also accelerate growth of the same students when they start learning at a faster pace. These adaptations come at no additional social costs to the children, such as changing their peers. It effectively ensures that students are not 'tagged' or fixed to one track, while allowing them to learn at their own pace. Secondly, refraining from commenting on the 'ideal' vision of how education systems should group children, a solution such as this allows nations to improve student learning without incurring heavy policy costs such as shifting away from the age-cohort based social grouping of students. In a way, it allows for governments to prioritize the right set of reforms at different stages of their own journey towards a transformational education system.

Before concluding, a fine reading of the study report also unpacks some very relevant lessons for governments thinking about implementing such systems. While the CAL system was pivotal in delivering improved learning, instructors may have a very important role to play in the overall implementation. For example, in the study, which was implemented in an after-school centre in Delhi, the EI instructor played a crucial role in encouraging regular student attendance, ensuring time on task, supervising school-homework completion and exam preparation during group-instruction period. Since some of these activities were demanded by parents, thinking through a holistic design of the intervention and obtaining buy-in from parents would be critical to successful implementation. In addition, the study also notes that the very nature of teaching-learning requires complex contextual-awareness and communication; thus, technology may serve to complement teachers, rather than substitute them. Secondly, parental demand for the Mindspark centres of the study was low in the absence of fee-waivers; thus, low-resource communities may not be able to access programs that charge a fee, and governments may need to think about delivering both hardware and software.

To summarize, the software's ability to instruct at the right level and pace, along with time-productivity considerations, and cost-effective and well-rounded implementation, make this a useful solution to test, implement, and iteratively improve in contexts with severe levels of inequity and resource constraints.

3.3. Aligning Actors

Reform components such as assessing learning and acting on available evidence are not effective in and by themselves. Any reform initiative needs to gain traction and sustain within the systems it is implemented in. For this to successfully happen, it is important to identify and map different actors, and align and equip them with the necessary skills and orientation to direct all inputs towards those outcomes. However, aligning actors and hence, systems, to absorb a new set of reforms is a challenging task. There are primarily two ways in which alignment may fail to take place. Firstly, accountability fails when different actors hold the system accountable to different goals. For example, while students and parents may value learning, governments and school bodies may value only appropriate budgetary allocation. Secondly, while governments may task schools and education departments with the goal of learning, the funding, information and incentives in the system may not be aligned to learning. For example, while schools or education departments may very easily produce enrolment data, they won't have information systems set up to produce such reliable learning data at high quality. Similarly, funding or retention of staff may not be linked to performance, but to other parameters, and thus, not incentivize learning. Thus, any reform initiative needs to be accompanied by an analysis that seeks to answer the following questions:

- Are all stakeholders aligned with the shifts that the reform seeks to produce, and hence, aligned on the data that they will use to assess and improve the reform?
- Is there adequate data on the outcomes that the reform seeks to achieve?

Therefore, it is clear that the power of using crucial levers of change, i.e. goals, financing, and incentives, is predicated on the easy availability of high-quality information. Technology can play a vital role in setting up the infrastructure in the form of Education Management Information Systems (EMIS) that can enable this. There are several examples[16] of successful building or consolidation of Education Management Information Systems (EMIS), including in Guatemala where data was made open to all through easily accessible website of the Ministry of Education; in Honduras where along with public access to data, relevant stakeholders were trained on using data; and Lithuania, where interest was generated among municipalities and school representatives, leading to the creation of local and school-level EMIS, and creation of an annual education report to measure student achievement. These are easily contrasted with examples that exhibited barriers such as lack of clarity on the goals and purpose (Albania, Vietnam, India), lack of political will (Bulgaria, Latvia), not equipping key actors or involving them in design and dissemination of data (Bulgaria, Vietnam, Pakistan, Chad, Ghana), and lack of legal framework that supports the EMIS (Bolivia and Argentina). What these numerous examples illustrate is the criticality of the process of reform, of the efforts to align for accountability, even in the creation of systems for tightening the very drivers of accountability.

One of the most critical design elements that enables a successful EMIS is reformers/practitioners supporting all relevant actors in identifying, articulating and prioritizing a problem, and then, helping create safe and conducive environments for iterative solutioning and innovation[17]. An example of this design principle is exhibited by an organization called Open Learning Exchange (OLE, Nepal) that has dedicated strategies for partnering with the community, government, schools and other expert organizations. These strategies aim to build alignment on the vision, strategy and design of the solution, promise and ensure commitment to sustain a high level of performance, and hold all parties involved accountable to outcomes. Therefore, to set in motion and sustain the virtuous cycle of assessing, acting and aligning actors towards learning, it is vital that all appropriate inputs are supported through alignment of all relevant actors, most importantly the school management, community, the education department, and local government.

Box 2: What about the ‘Disruptive Technologies’?

Disruptive innovation theory, first introduced in the mid-90s, describes innovations that originate in low-end *footholds* in existing markets (where incumbents typically focused on

[16] (Abdul-Hamid, Saraogi, & Mintz, 2017)
[17] (Andrews, Pritchett, Samji, & Woolcock, 2015)

their most profitable and demanding customers and paid less attention to less-demanding customers) or that create new-markets as footholds[18]. Some of these innovations 'sustain' if they continue delivering better products and services, generally at lower costs, than incumbents and become mainstream. It is rare that a technology or product is *inherently* sustaining or disruptive; disruption is a process, and smart disrupters improve their products and drive upmarket.

While analyzing industries, therefore, it is pertinent to discuss 'new technologies', monitor their trajectory, and see if they emerge as successful disruptors over a period. Michael Porter, a Harvard Business School professor, analyzed the advent of new technologies as consisting of three 'waves'[19]. Wave 1 (1960s and 1970s) automated individual activities in the value chain, such as bill payments, maintaining records, computer-aided design etc. They largely improved the periphery of the education system by enhancing the productivity of certain activities. Wave 2 (1980s and 1990s), powered by the rise of the internet, led to coordination and integration across individual activities with outside suppliers, channels, and customers; and across geography. It allowed universities, for example, to closely integrate research networks.

Wave 3 of technology being unleashed now is about technology becoming an integral part of the product or service itself. Embedded sensors and processors power products in the augmented reality and virtual reality domains; cloud computing and internet of things connect products in never-imagined ways; big data powers dramatic software applications in artificial intelligence and machine learning; and ledger technologies such as blockchain can fundamentally transform transactions. Very early experiments with some of these in the education system also exist. Augmented reality headsets have promised 'immersive' learning experiences, machine learning algorithms have been deployed to predict student outcomes, and blockchain-based educational certificates are already being piloted.

Has the education industry been 'disrupted' in the past? Perhaps history holds a lesson. Johann Gutenberg's invention of the printing press in mid 1400s disrupted the access to information, which was earlier limited to copying and production of the written word into laborious manuscripts accessible to wealthy elites. Technology to create nearly identical

[18] (Christensen, Raynor, & McDonald, 2015)
[19] (Porter & Heppelmann, 2014)

books of quality at an economical price created a massive new-market foothold: the general public who were non-consumers of books. This disruption shifted the entire educational practice in the world: the relationship between the educator and student now had a third ingredient - technical texts as silent instructors.

Will the onslaught of the third wave of technology disrupt education value chain (and at several points)? Like most cases of possible disruption, it is too early to say. Large-scale education has been an extremely resilient enterprise in that sense. Part of the reason is that it is hard to find examples of disruptive innovation in the public sector, which constitutes a major chunk of basic education delivery around the world. Several factors, such as profit motives and competitive pressures propel disruptive innovations in the private sector, but are largely absent in the public sector. Even when the public sector is innovating, the most common types of innovation often drive costs up[20], as they tend to add increasingly complex and expensive features onto existing innovations (think of introducing smartboards in classrooms). In such 'traditional' innovations, price vs performance is a trade-off: it is generally assumed that better performance requires more teachers, smaller class sizes, and better facilities (i.e. paying higher price). Disruptive innovations need to break such trade-offs and reduce costs by finding *footholds*, i.e. a population of underserved/unserved consumers, and then going mainstream. 'Online education' models (such as Massive Open Online Courses, or MOOCs), might have found such a new-market foothold by targeting non-consumers of education. If online education products continue to improve and get driven upmarket, we might have a case of successful disruption.

Amidst the rapid technological progress of the present millennium, one thing is certain: the status quo of the education enterprise might, finally, be changing.

4. Conclusion and food-for-thought for policymakers

"If all you have is a hammer, everything looks like a nail."

[20] (Eggers, Baker, & Vaughn, 2013)

– Abraham Maslow

The challenges faced in education are multi-dimensional, and vary immensely from region to region, many a times within the same country. Over the past two decades, a number of ICT tools have been developed and implemented in the school systems around the world. However, technology – no matter how well designed – is only a magnifier of human intent and capacity; it is not a substitute[21]. It is often tempting to think of ICTs as a silver-bullet solution, and jump to the debate on specific inputs (what kind of laptops should I buy?) that might have worked elsewhere (most likely the evidence being from highly developed learning environments). But acquiring the technologies themselves, no matter how hard and expensive, may be the easiest and cheapest element in a series of elements that ultimately could make these technologies sustainable or beneficial.

Effectively integrating technology into educational systems is much more complicated. It involves a rigorous analysis of educational objectives and changes, a realistic understanding of the potential of technologies, a purposeful consideration of the pre- and co-requisites of effectiveness of ICTs for education, and an assessment of the prospects of this process within the dynamics of educational change and reform. The impact of ICTs for education depends to a large extent on the purpose for which ICTs are used. For example, if technology is used to stream recorded lectures/videos of existing teachers, and software is used to merely provide digital copies of existing textbooks, it is far-fetched to expect learning results significantly different from classroom lecturing or textbook use. However, these instructional technologies may extend educational opportunities to situations where there is no lecturer or textbook. In simple terms, understanding what one wants to accomplish, understanding the users and beneficiaries, and understanding the relevant "use cases", is the key. Development efforts utilizing ICT tools that are more likely to succeed are informed by co-creation and take place as close to the user as possible.

Integrating technology into the educational process is an intricate, multifaceted process that involves a series of deliberate decisions, plans, and measures. As evidence[22] indicates, scaling any intervention from a 'proof of concept' stage requires multiple iterations of experimentation, in which underlying mechanisms are identified and the model is refined

[21] (Toyoma, 2015)
[22] (Banerjee, et al., October 2017)

based on this understanding. The following[23,24] might serve as a step-by-step guide to policymakers when thinking about ICT-enabled improvement of school education systems:

- Create a vision for ICT use in education, identifying educational areas for ICT intervention, formulating ICT-in-education policy, and articulating *what* precisely will the ICT intervention change/enable

- Understand the current context, for all aspects identified in the vision for ICT use in education, so as to identify/build the 'right technology', and then develop an implementation strategy that helps achieve the vision, by accounting for challenges and leveraging strengths of the current system
    - Consult a range of actors, such as students, parents, teachers, teacher trainers, administrative officials, and civil society organizations
    - Identify challenges and strengths related to the quality and relevance of content, ease and cost of set-up and maintenance of infrastructure, hardware and software, and knowledge, skills and mindsets of relevant actors
    - Empower all key actors associated with the education system towards performing their duties and realizing their aspirations
    - Train relevant actors, support them in deploying technology and create the necessary culture for the use of ICT through awareness drives across the system
    - Proactively create adequately contextualized and tested content/reports/outputs that will form the heart of the intervention
    - Allocate funds for maintenance and update of the infrastructure, i.e. both software and hardware
    - Prioritize pro-equality as a fundamental tenet of the strategy

- Monitor, evaluate, continuously learn, and improve design and implementation
    - Allocate adequate funds and resources to the creation of an MIS that serves as a backbone, enabling the collection, aggregation, storage, analysis and synthesis of data towards improvement of the design and implementation of technological solutions, programs and policies; evaluate for impact

[23] (Trucano, 2016)
[24] (Information for Development Program (infoDev), 2007)

- Build sufficiently exhaustive practices that ensure data security and pack appropriate privacy provisions

All the above steps might not be relevant in every context, but it is necessary to think of a 'big picture' even with smaller interventions.

Technologies have great potential for knowledge dissemination, effective learning, and efficient education services. However, to truly realize this potential, the educational policies and strategies need to be right, ICT-in-education policies need to be well thought out, and the prerequisite conditions for using these technologies must be met concurrently.

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