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Educational technology in developing countries: a review of the evidence

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Abstract: the emergence of educational technology ("EdTech") in developing countries has been received as a promising avenue to address some of the most challenging policy questions within educational systems. In this paper, I review and synthesize all existing studies with credible causal identification frameworks of EdTech interventions in developing countries. While other studies review the evidence for EdTech interventions in developed countries, there is currently no equivalent study for developing contexts, in spite of the rising number of studies being produced. I classify studies into four thematic categories based on the type of EdTech intervention analyzed: (1) access to technology, (2) technology-enabled behavioral interventions, (3) improvements to instruction, and (4) self-led learning. I find that EdTech interventions centered around self-led learning and improvements to instruction are the most effective forms of EdTech at raising learning outcomes. Similarly, technology-enabled behavioral interventions are less promising for generating large effects but highly cost-effective given their typically low marginal costs. While expanding access to technology alone is not sufficient to improve learning, it is a necessary first step for some other types of interventions. More broadly, the overall success of interventions rests on the thoughtful customization of the EdTech solution to the policy constraints at hand. Finally, EdTech interventions across all thematic areas can and should act as complements by leveraging their respective comparative advantages to address deficiencies within educational systems in developing countries.

Keywords: EdTech, education policy, developing countries, innovation, scalability, cost-effectiveness

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I. Introduction

As technology evolves, the frontier of its potential applications also expands. The education sector is no exception to this, and technology has become an ever more basic input into the provision and growth of educational services over the past decades. With recent expansions of the education systems in many developing countries, and the accompanying lagging outcomes in terms of learning, retention, graduation rates, and socioeconomic equity, investments in educational technology or "EdTech" are regarded as a promising option to boost these outcomes. In particular, I define EdTech as any application of information and communication technologies in education. This includes, but is not limited to, the distribution of existing technology[1], the provision of devices with tailored software[2], the adaptation of existing and already-owned technologies[3], or the use of specialized software in communal computers[4]. Through this working definition, the current study attempts to capture the breadth and depth of the current landscape of EdTech in developing countries, in terms of actual products, but also markets, countries, and target populations.

Before adopting and adapting EdTech interventions, policymakers and educational stakeholders need to be informed about what kind of EdTech interventions have displayed the most promise for different outcomes, populations, and sets of circumstances. Given the wide-ranging and emerging nature of the EdTech field, locating and analyzing all the extant EdTech literature is not a trivial step for researchers and practitioners alike. As a response to this need, Escueta et al. (2020) offers a thorough example of a meta-review that surveys EdTech's effects on educational outcomes, focusing on developed countries. However, the most pressing challenges in the educational systems of developing countries look very differently from those of developed countries. Furthermore, the kind of EdTech intervention that could actually be deployed in different contexts is very different due to issues related to access to technology and public infrastructure. As a response to all these factors, Escueta et al. (2020) mention that "after considering both literatures, we determined that the circumstances surrounding the ed-tech interventions that have so far been experimentally studied differed too greatly across developed and developing country education systems to allow for integrating findings from both in a way

[1] For example, the laptops in Beuermann et al. (2015).
[2] For example, the tablets in Pitchford (2015).
[3] For example, the use of SMS texts in Berlinski et al. (2016) or T.V. programming in Borzekowski (2018).
[4] For example, the after-school program evaluated in Böhmer et al. (2014).

that would yield meaningful policy implications.” In short, the actual effectiveness and focus of successful EdTech interventions in developed countries may translate to very different results in developing countries, calling for an urgent need to understand the patterns within the EdTech literature focusing exclusively on developing countries.

To shed light on the promise and limitations of EdTech specifically in developing countries, the current review synthesizes the patterns and lessons found in the extant literature rigorously evaluated in low- and middle-income countries. The search methods included thorough searches in scientific repositories, working paper series from renowned research and international organizations, forward and backward tracing from key papers, and from all papers that were being subsequently added to the list. In all, this review identifies 81 “core studies” across 36 low and middle-income countries since 2002[5], spanning 5 different methodologies, with 3 in 4 being randomized controlled trials. In order to thematically group findings, the core studies are organized and analyzed thematically across four different areas: (1) access to technology, (2) technology-enabled behavioral interventions, (3) improvements to instruction, and (4) self-led learning. The specific research questions explored throughout this review are (1) across what particular thematic areas and outcomes of education has EdTech displayed the most promise in developing countries?, (2) what type of EdTech interventions does the current literature suggests that has little to no effectiveness on learning?, (3) under what contextual circumstances do the different types of EdTech interventions work best in developing countries?, (4) what are the current gaps and frontiers in the scientific knowledge about EdTech in developing countries?, and (5) how do different cost structures and levels of cost-effectiveness influence the potential for scalability of an intervention?

II. Why EdTech in developing countries?

EdTech has started to play a role in the education of millions of children in developing countries. The Chinese market almost reached USD 2 billion in early 2019[6] and by some estimates, the Indian market is expected to reach this mark by 2021 (Sampson, et al., 2019). Globally, the EdTech industry was valued at USD 17.7 billion in 2017, with expectations for a quick increase in value in following years[7]. The role of EdTech in children’s lives became more salient during

[5] There was no restriction on search date. 2002 is simply the year of the earliest paper found.
[6] Source: EdSurge. “Chinese Edtech sees $1.86B in Q1 2019, Bucking Plummeting Venture Trend” (May 27, 2019).
[7] Source: Frost & Sullivan. “Growth Opportunities in the Education Technology Market, Forecast to 2022” (December 15, 2017).

the school closures induced by COVID-19 pandemic worldwide, where governments, and international organizations called for EdTech solutions as part of the bundle of at-home activities children might have available to minimize learning losses. In spite of the growing influence of the industry, this expansion does not reflect other important metrics such as a more egalitarian reach to all learners in developing countries, or the incorporation of rigorously-tested technologies. A recent analysis of the EdTech Hub database with EdTech firms from around the world (Crawfurd, 2020), shows that only 19 million out of over 450 million children in Africa were using any kind of EdTech before the pandemic. Furthermore, most of these users are concentrated around a few leading companies in a handful of countries, or around students watching educational programs on T.V. Over half of all EdTech firms serving developing countries, based on a widely-publicized database, are located in just three countries: South Africa, Kenya, and Nigeria.

Similarly, Crawfurd also points out that the potential market size matters for the extent to which EdTech innovation develops. The most obvious driver of market size is the number of young people in a country, as Crawfurd shows. However, the potential market size could be driven by other factors such as language or household income. Developing an app that promotes early literacy in English or Kiswahili will have a much larger potential market than an app promoting the same outcome but in Xhosa. While shared languages across countries might incentivize EdTech developers to produce tools tailored to these major languages, it could also lead to intra-country inequalities for minority language speakers. Similarly, the presence of emerging purchasing power from low and middle-class families can play a determinant role in the decision to invest in an EdTech product. While countries with large populations like the Democratic Republic of the Congo, Ethiopia, or Bangladesh may benefit from investments in EdTech, the very low average household income, even for the standards of developing countries, might make it less appealing for private companies to invest in those contexts. Likewise, given that the EdTech industry is mostly driven by the private sector up to this point, these inequalities could also emerge at an intra-country level from differences in disposable income across socioeconomic groups, increasing prevalent educational gaps within countries.

There are reasons to be both optimistic and skeptical about the effectiveness of EdTech in developing countries. While the relatively low levels of access to inputs such as electricity, the internet, and hardware might be challenges that hinder EdTech's promise, EdTech may also be particularly well-suited to address some of the most critical educational questions in these contexts.

In particular, EdTech could be leveraged to address problems that would be too costly or resource-intensive to solve through other channels. For instance, EdTech could be adopted to address issues of appropriately-leveled education to deliver instruction and practice problems tailored at each student's specific level. Such a challenge would be almost insurmountable with the current incentives and levels of educational resources, in contexts with already extremely high pupil-teacher ratios. EdTech could also be used to address issues of stakeholder accountability, such as with the implementation of cameras that monitor teacher absenteeism, and replace less-frequent but more-expensive school inspections. Furthermore, EdTech could be used to address some of the input shortages that many schools face. Simple handheld devices could be used to replace lacking inputs such as computers, textbooks, notebooks, teacher records, and teaching guides, as a single device could perform these functions by holding many documents at once. However, the effectiveness and cost-effectiveness of all these interventions has not been systematically reviewed, and hence remain an open empirical question.

On the other hand, EdTech could face important shortcomings both in terms of take-up and implementation in developing countries[8]. One initial challenge is that the low levels of penetration of other technologies could hinder the level of familiarity with the platforms on which EdTech tools are deployed, and hence obstruct the effectiveness of an otherwise well-designed intervention. While most countries are approaching universal access to electricity, Sub-Saharan Africa still stands at 48%, lagging far behind 98% in Latin America and the Caribbean, and 92% in South Asia (World Bank[9]). Only 1 in 4 people in Sub-Saharan Africa have access as of 2018, and in India alone there were 475 million people not using the internet in 2018 (World Bank[10]). At the even more local level of schools, there are large global gaps in terms of access to technology. For example, in Cambodia, Nepal and Myanmar, less than 10% of all primary schools have access to electricity (UNESCO[11]). Less than 10% of all schools have access to the internet in Sri Lanka, the Philippines, Kyrgyzstan, and Bangladesh (UNESCO[12]). Even the presence of computer hardware at the school-level is rare in some countries: in Niger and Zambia, there are over 500

8 Given the many avenues in which EdTech solutions can be implemented, and the broad nature of this review, it is impossible to establish an absolute threshold for the needs that households, schools, or educational systems must have met before adopting an EdTech product. However, most EdTech tools do require either access to connectivity features like electricity, internet, mobile coverage, a broadband connection, and/or access to hardware such as computers, cellphones, or tablets. Clearly, the extent to which these technologies are readily available in an area will heavily influence both the feasibility of implementing an EdTech intervention, and the kind of EdTech interventions available for policymakers to choose from.

9 World Bank Development Indicators: Access to electricity (% of population), 2018.

10 World Bank Development Indicators: Individuals using the Internet (% of population), 2018.

11 UNESCO Institute for Statistics: Proportion of schools with electricity and telephone communication facilities, 2012.

12 UNESCO Institute for Statistics: Proportion of educational institutions with Internet access, by type, (primary and secondary) 2012.

students per computer in a school, and in India, fewer than 20% of all schools have hardware for individual-use products (Sampson et al., 2019). Naturally, access to technologies is not only an issue of inequality between countries, but also within countries. While these intra-country inequalities can be ameliorated by higher levels of penetration, some of the most common inputs in EdTech interventions are still unlikely to reach the most deprived sectors of society in developing countries. In countries like Mexico or Peru, 94% households in the top income quintile have access to computers at home, while less than 10% of all households in bottom income quintile do (Rieble, et al., 2020). Moreover, it is often the case that these technologically-disadvantaged groups within each country are also those for which the educational outcomes lag the most. These are critical considerations for the study and implementation of EdTech interventions in developing countries: EdTech program administrators will need to either assess and cater to the local supply of technological tools, or incorporate the provision of infrastructure and hardware.

Similarly, implementation of even well-designed programs could be especially difficult in areas with weak state capability. Either through explicit corruption leading to leakages of equipment and funds, or through poor executing capacity, weak state capacity may be a barrier towards fruitful investment in EdTech. The most cynical view is that if these governments have not been able to provide other basic inputs like textbooks and chalk to all schools, the extent to which they can deploy successful EdTech interventions is highly questionable. In all, this review examines the extent to which EdTech can address some of the most serious educational challenges in developing countries, and how it could also be hindered by specific contextual factors.

III. Overview of methods for this review

This paper is conceptualized as a comprehensive review of the evidence in developing countries. As such, extensive search methods with clear inclusion criteria were employed. The inclusion criteria spanned papers which use experimental or quasi-experimental evaluation methods, involved a technological tool to address a policy issue around education, and that were set in a developing country. There were no restrictions on the publication stage, academic field, or data of publication. This search yielded 81 eligible papers. An online appendix contains detailed descriptions of the search methods, inclusion criteria, and characteristics of papers included. Similarly, the online appendix contains the full coding, and summary tables of all papers.

The studies identified reflect significant diversity in the types of treatments, contexts, targeted stakeholders, and scale of interventions. To thematically group the patterns in the literature, I followed a similar classification to that used by Escueta et al. (2020). I classify papers into the mutually-exclusive categories four broad thematic categories based on the design features and educational goals of each intervention: "Access to technology", "Technology-enabled behavioral interventions", "Improvements to instruction", and "Self-led learning". Interestingly, Escueta et al. (2020)'s four thematic categories do not fully overlap with the categories for this review[13], as the type of intervention and issues addressed in the current body of literature varies greatly between developed and developing countries. In practice, studies may not neatly or exclusively fit into one category or the other. For instance, an argument could be made that all the "One-Laptop-per-Child" (OLPC) interventions like Beuermann et al. (2015), Cristia et al. (2017), de Melo (2014), and Cordero-Meza (2017) were ultimately about "self-led learning" at home, not necessarily access to technology. However, given that the most proximate goal of the project was to increase children's access to technology, these were categorized as "access." Ultimately, this classification allows for a broader exercise of finding patterns and policy lessons across similar interventions, which is the goal of the current paper.

IV. What are the main patterns in the existing literature?

a. Access to technology

Much policy and research attention has been devoted to the issue of access to technology. In fact, approximately one fourth of reviewed studies focused on access to technology. In theory, access to EdTech could ameliorate the prevalent lack of other inputs like books, blackboards or notebooks by consolidating these inputs into single devices that can be used by several students. The lack of these traditional inputs in the developing world can be very binding. In Niger and Nigeria, less than half of all students had paper to write on, and in Togo there were approximately 66 students per math textbook (SDI). Similary, between 2013-2016 only 1 in 5 schools in Tanzania had a library with books (Mbiti et al, 2019a; Mbiti et al, 2019b; Mbiti et al, 2019c). These large global inequalities in access have motivated initiatives such as the highly popular "One-laptop-per-child" (OLPC), where governments, donors and NGOs aim to have a computer-pupil ratio of

[13] Escueta et al. also use the "Access to technology" and "Technology-enabled behavioral interventions" categories. Their "Computer-assisted learning" was replaced for a broader "Self-led learning", which also included their "Online learning" category. Finally, there were enough interventions in the "Improvements to instruction" category that did not neatly fit into the other categories, which also deserved a separate category.

one to one, either through direct provision of laptops to students or through classroom sets large enough for each child to have a laptop to themselves. Investments to increase students' access to technology at school have also become a clear policy priority for even the lowest-income countries (Kozma and Surya Vota, 2014). In spite of the push to improve access to technology, the evidence of its effectiveness to improve learning is at best mixed, and realistically does not suggest that the mere provision of technological tools translates directly into higher academic achievement. For instance, none of the evaluations of the OLPC initiatives across Latin America found significant results on scholastic outcomes (Barrera-Osorio and Linden (2009) in Colombia; Beuermann et al. (2015), Cristia et al. (2010, 2017), in Peru; de Melo et al. (2014) in Uruguay, Meza-Cordero (2017) in Costa Rica). Similarly, a long-term follow up of the OLPC in Uruguay also finds null results on educational attainment (Yanguas, 2020). Similarly, Bando et al. (2017) finds that replacing regular textbooks for laptops in Honduras had no statistically-significant effect on learning, and costs about USD 48 more per student than the status quo. A qualitative study in Brazil (Lavinas and Veiga, 2013), not included in the set of core studies, also reviews the results of OLPC initiative in Brazil, and finds that the persistent under-utilization of the computers and lack of teacher training on how to incorporate the equipment into daily instruction hindered the potential of the project. Similarly, Barrera-Osorio and Linden (2009) find that the most problematic step is the actual incorporation of computers into the instructional process.

The presence of null results for most OLPC interventions does not necessarily imply that if students are provided with computers, they did not use them: in spite of the lack of positive effects on grades, Meza-Cordero (2017) finds that OLPC students experienced an increase in the amount of time they spent using a computer, at the expense of time doing other activities like homework and outdoor activities. Indeed, studies such as Angrist and Lavy (2002), and Malamud and Pop-Eleches (2011) find *negative effects* on academic outcomes as a result to the provision of technology to students. In spite of the negative to null effects on academic learning as a result of increasing access to technology, there is evidence to believe that this kind of intervention can improve computer skills and familiarity with technology. In particular, Mo et al. (2013), Bet et al. (2014), Malamud et al. (2019), Malamud and Pop-Eleches (2011), and Beuermann et al. (2015) find that the exposure to technology led to an improvement in familiarity with technology, up to an increase of 0.30 SD in "digital skills" in the case of Bet et al. (2014). If digital skills are also considered a valuable outcome from this type of intervention, then there is more evidence to suggest that exposure to tools like computers naturally increases students' familiarity with technology and digital skills than there is to suggest that these technologies can raise test scores by themselves.

There were four interventions providing handheld devices, with more mixed results than the provision of computers. While Pitchford (2015), and Mensch and Haberland (2018) find positive effects on learning of the handheld devices, Habyarimana and Sabarwal (2018) find null effects. Piper et al. (2016) find that the treatment arms providing a literacy program plus handheld devices for teachers or students were at most as effective, and less cost-effective, than the base literacy program. Among these four interventions, the two with the strongest case for the use of technology, Pitchford (2015), and Mensch and Haberland (2018), also had an important element of in-person support. In the case of Pitchford (2015), teachers and volunteers supported the use of the tablets with mathematical content, and in the case of Mensch and Haberland (2018), the provision of e-readers was complemented with routine group meetings. On the other hand, a treatment branch of Habyarimana and Sabarwal (2018) included content tailored to the national curriculum, but there was no in-person support for the users of the handheld devices. These results highlight again that the mere provision of hardware may not be enough, if it is not accompanied by proper in-person pedagogy or encouragement.

The most salient exceptions in terms of raising student achievement levels within the category of access to education were the three papers looking at the effect of large-scale interventions providing high-level access to technology. Specifically, these three papers were Kho et al. (2018), with the large-scale provision of internet access in public schools in Peru; Navarro-Sola (2019) in in the case of *telesecundarias*[14] in Mexico; and Seo (2017) with the electrification and provision of instruction-enhancing tools in Tanzania. All of these interventions were targeted at a much larger scale than specific individuals or schools, and consisted of helping deprived regions catch up technologically with other areas within the country, as opposed to the provision of more advanced technologies which are not as widespread within each country, such as OLPC. These interventions may be suggestive evidence that large-scale infrastructure-enhancing interventions in underprivileged areas may be effective in complementing students' education and narrowing within-country inequalities, such as in the case of Seo (2017) and Kho et al. (2018).

[14] According to the author of the study, "Telesecundarias are a type of junior secondary school that delivers all lessons through television broadcasts in a classroom setting, with a single support teacher per grade. The televised content follows the national curriculum and is complemented with learning guides and in-classroom work and discussions."

Similarly, in spite of the global increase in school enrollment, many countries have not achieved universal enrollment, and these “last-mile-enrollments” may indeed be the hardest to enroll. In areas of high remoteness and low population density, a formal school may be logistically difficult to establish. In these cases, policymakers and researchers alike will need to consider alternate solutions, including EdTech interventions like *telesecundarias* if the infrastructure allows it, to achieve universal enrollment.

In all, it seems unlikely that the mere provision of hardware will yield improved learning outcomes, as Sampson et al. (2019) also point out. In fact, the median effect of all the studies included in this category is an imprecise null effect. Even more importantly, when these interventions are provided at the student-level like in Angrist and Lavy (2002), or Malamud and Pop-Eleches (2011), as opposed to the mass construction of infrastructure, they also tend to also be very costly. The very low gains in learning coupled with the high price tag of these interventions should make policymakers weary of programs that simply increase access to technology, with the important exception of programs that are explicitly intended to increase digital skills. Access to technology is a necessary, but not sufficient, requirement for the implementation of other kinds of EdTech interventions. This finding agrees with other comprehensive reviews of evidence, which have found that interventions that simply address these input constraints through “supply-side” provisions (Masino and Niño-Zarazua, 2016; McEwan, 2015; Murnane and Ganimian, 2016; Glewwe and Muralidharan, 2016), by lowering implicit and explicit costs of schooling (such as the provision of school uniforms, as in Evans and Ngatie, 2020), or by providing better school supplies (as in Glewwe et al., 2009), do not lead to improved learning.

While inputs themselves may not be enough to raise learning standards, they can act as augmenting complements to any learning-oriented intervention, including EdTech (Sampson et al., 2019). As long as interventions that increase access to technology are either well-accompanied by pedagogical tools, or designed as a stepping-stone for other type of interventions, they should remain in the menu of options for policymakers in some form. Still, policymakers should also consider the trade-off of implementing interventions that increase access to technology to then implement another type of EdTech intervention, versus simply designing the second intervention around more prevalent technologies such as SMS messages, phone calls to feature phones, or radio instruction[15].

b. Technology-enabled behavioral interventions

Shaping human behavior is a less straightforward endeavor than the provision of technological inputs. This requires deep knowledge about the specific constraints to be relieved, the availability of a channel through which behavior-shaping incentives can flow, and a well-designed intervention informed by a credible theory of change. Nevertheless, interventions that incentivize behavior are promising avenues to shape systemic issues in a cost-effective manner. In this section, I begin by reviewing interventions aimed at affecting teacher behavior, and then interventions that curb parental and student behavior.

High rates of teacher absenteeism, and low rates of on-task instruction are an ingrained and prevalent policy issue in many developing countries. For example, the teacher absenteeism rate was around 24% in India in 2010, representing a fiscal burden of about USD 1.5 billion per year (Muralidharan, et al., 2010). In Kenya, only 43% of the time during which teachers are expected to be teaching is spent actively engaging in class, and in Mozambique, students only get about 1 hour and 33 minutes of instruction every day due to the low rates of instructional on-task time from teachers (SDI). This policy challenge was tackled by both Gaduh et al. (2020) in Indonesia, and Duflo et al. (2012) in India, by providing cameras with timestamps, and teachers were required to take frequent pictures with their students to prove that they were indeed in school. Furthermore, both interventions conditioned at least a portion of the teacher's pay to their presence in school, as verified by the cameras. Both interventions proved effective, raising students' test scores by 0.17-0.20 SD. In the case of Gaduh et al. (2020), the treatment arm with the camera was one of the treatment arms (among others) which also sought to increase school-level accountability such as the public dissemination of scorecards. Although the camera treatment arm was the most effective at raising student outcomes, the other two treatment arms were also effective. Furthermore, there was suggestive evidence that the camera indeed led to changes in teacher behavior, emerging as a potential mechanism for the increased test scores. These findings stand in sharp contrast with other more traditional channels expected to increase teacher effort such as salary increases. In fact, an intervention that *doubled* teachers' salary on a permanent basis in Indonesia (de Ree, et al., 2018)

[15] For instance, see Trucano (2010) for a high-level overview of radio instruction programs, and Ho and Thukral (2009) for an overview of the evidence on the effectiveness of radio instruction.

led to precise zero improvements in student learning. In this sense, EdTech could prove a valuable tool in shaping teacher accountability and performance, and potentially even more so than other traditional channels like salary increases, if the right behavioral constraints are targeted by the technology.

In spite of these successes, implementation and take-up do play a major role in the success of this kind of intervention. For instance, Adelman et al. (2015) implemented an intervention in Haiti which had as one of its components a platform where teachers could send daily photographs to verify their presence, similar to Duflo et al. (2012) and Gaduh et al. (2020). The authors highlight the very low take-up of the program, and serious logistical challenges at the time of implementation, ended up hampering the effectiveness of the intervention. For instance, the authors mention that “The program faced challenges from the start, including delays and technical problems that made it hard to implement it as planned” and “There were so many problems getting schools ready for the pilot that the program ended up starting months late […] This short implementation period reduced the chance of seeing any change in teacher behavior or student learning". Therefore, even if the behavioral intervention is grounded in the context-specific constraints, and properly designed based on a realistic theory of change, the support of partners on the ground to ensure compliance is also key. These considerations around implementation should be taken seriously, particularly in contexts where state capacity is weak.

In terms of interventions that are intended to provide information as opposed to increase accountability, there are several examples of interventions that were effective, and highly cost-effective. At the parent-level, Berlinski et al. (2016) evaluate a program which consisted of high-frequency texting campaigns for parents in Chile, during which they were informed about their children’s performance, attendance, and behavior. The study finds large effects in test scores and attendance after only four months of the intervention, highlighting the crucial role that solving information asymmetries between parents and students can play in keeping students accountable for their school performance. At the student-level, interventions like Neilson et al. (2018a, 2018b) address information asymmetries about the perceived returns to education (such as those documented in Jensen, 2010), and provided students with information on the actual returns to education through contextually-sensitive videos and infographics, which also had significant effects on the students’ performance and aspirations. Similarly, Riley (2017) leverages “role model” effects through the showing of the movie “Queen of Katwe” to Ugandan students, with positive results in the short term. At the teacher- and school officer-level, interventions like Dustan et al. (2019), and Vakis and Farfan (2018) also proved successful by sending these stakeholders SMS messages with things like reminders about deadlines, framed using insights from behavioral science such as the inclusion of the recipient's name in each text. Although most of these informational campaigns have effects on the smaller side (i.e. less than 0.10 SD), it is also noteworthy how inexpensive and scalable these interventions really are. Once a system that automates the sending of messages through platforms like WhatsApp or even SMS is in place, the marginal cost of adding new users is extremely low.

In sum, the extant evidence suggests that properly designed and implemented technology can shape the behavior of education stakeholders in a way that can be scalable and cost-effective, and is indeed a promising area for future research. Given the smaller size of the effects of information campaigns, this type of intervention does not emerge as a promising lead reformer of educational systems in developing countries. However, their high cost-effectiveness and potential for scalability emphasizes the need to complement other core educational policies with this kind of intervention, which bridges gaps in knowledge and cognitive bandwidth. An important feature shared by all these studies was that the information provided is actionable, relevant for the specific context, and concrete-enough to not overwhelm the recipient, therefore making the translation between new information and improved educational practices easier. Similarly, interventions aimed at improving accountability around the stakeholders of education seem promising, albeit more sensitive to challenges with implementation, monitoring, and scalability. If implemented correctly, these can achieve large gains in academic outcomes such as in Duflo et al. (2012), and very high cost-benefits ratios such as in the case of Aker and Ksoll (2019). However, the support of local partners to design, deploy, and incentivize the take-up of the intervention is crucial, as best exemplified by Adelman et al. (2015). Instead of a unified global agenda, this particular area calls for in-depth knowledge of contexts, and local constraints which may be alleviated through technology-led interventions. Having said this, options such as the use of technology to aid parents directly support their children's studies such as in Doss et al. (2018), and the potential for technological channels to inform students about opportunities and deadlines to further their education such as in Castleman and Page (2015) remain fairly unexplored in developing contexts.

c. Improvements to instruction

The "improvements to instruction" category includes all interventions aimed at addressing any of the constraints that make the quality of teacher instruction not the best that it could be at boosting learning outcomes. Within this category, I have identified three main sub-themes: remote instruction, shaping of classroom instruction, and remote engagement with teachers and parents. As such, the first sub-theme deals with connecting students with knowledgeable, engaging, and curriculum-specific remote instruction. Even when teachers are actively engaging in class, their instruction could be hindered by their lack of mastery in the content knowledge. For example, only 2 in 3 teachers in Kenya, achieve minimum proficiency in the content they are supposed to teach, and in Madagascar, less than 2% of all teachers achieve this threshold (SDI). Therefore, even if teachers are engaged in teaching, these numbers question the extent to which teachers, themselves the product of these educational systems, also possess the foundational numeracy and literacy skills they are expected to nurture in their students. The issues around teacher mastery of the content run deep within the structural setup of educational systems. Factors such as teacher recruitment and deployment in "undesirable" areas such as remote regions or places of extreme deprivation, lack of regional teacher formation centers in the more rural areas, and lack of incentives for professional development may also play a crucial role in this issue and widen intra-country inequalities[16]. In this sense, EdTech could step in as a complement or as a substitute for classroom instruction to fill in content gaps teachers may have, and a substantial portion of the literature has focused on using technology to bring education to the remote places, or schools with generally weak-performing teachers.

Johnston and Ksoll (2017), Naik et al. (2016), and Bianchi et al. (2019) evaluate the impact of remote instruction via satellite in Ghana, India, and China respectively. Interestingly, remote instruction has a long history in development studies: one of the main precursors of RCTs in their current form was a study on math instruction using radio broadcast in Nicaragua in 1974 (Searle, 1975). As an illustration of the modern form of these interventions, Johnston and Ksoll (2017) evaluated the broadcasting of live instruction via satellite to rural primary school students, from a recording studio in Accra where qualified teachers would lead the lessons for students in grades 2-4. All three studies find significant learning gains in at least one subject. Furthermore, their cost-effectiveness is promising, especially since most of the costs are fixed, making the marginal costs

[16] For instance, see Huang et al. (2020) for a clear illustration of serious teacher recruitment issues in Indonesia.

of additional students or even classes very low. Among these, Naik et al. (2016) is particularly remarkable due to their explicit decision to study a program at-scale, reaching almost 2,000 public and private schools across the entire state of Kartanaka. By implementing this program at scale, the authors lower their per-pupil costs to less than USD 2 per year, without necessarily compromising the strong learning gains in the order of 0.10 SD-0.40 SD (depending on the subject). The model of remote instruction was not exclusively tested for live lessons, but also through audio and video recordings. Studies like Beg et al. (2019), Näslund-Hadley et al. (2014), and Wennersten et al. (2015), in Pakistan, Paraguay, and India respectively, also studied the effect of delivering content that complements classroom instruction through pre-recorded content. For example, Beg et al. (2019) delivered expert content through pre-recorded content tailored to the local context, which replaced regular class time and gave teachers tools to review the content of the videos through multiple-choice testing. Näslund-Hadley et al. (2014) was also an intervention with a high degree of local adaptation, as the content of the recordings followed the national math curriculum for preschool, and was taught bilingually in Spanish and Guaraní to mimic the teaching conditions of Paraguayan schools. Along the same lines of pre-recorded videos, the different evaluations of local adaptations of Sesame Street for different contexts (Borzekowski (2018) in Tanzania, Borzekowski and Henry (2010) in Indonesia, Borzekowski et al. (2019a) in Rwanda, Borzekowski et al. (2019b) in India) also all had positive effects on early numeracy and literacy skills of young children. Finally, Angrist et al. (2021) explore the effectiveness of phone-based instruction in Botswana during COVID-induced school closures, showing benefits in the order of 0.12 SD for a weekly 15-20-minute call during 12 weeks. This model seems especially appealing during emergencies as calls must be tailored to each student's level, and feature phones are highly prevalent in the developing world.

The second sub-theme within this category was the complementing and shaping of teacher instruction, as opposed to substitution. The most fitting example is Böhmer et al. (2014), which studied an after-school computer-assisted program in Cape Town focusing on each student's particular weaknesses in math, and giving students agency to pick whichever topics they wanted to work on. This program proved effective at improving math knowledge, and interestingly, it raised foundational math knowledge more than it improved the grade-specific knowledge of students. In other words, by fully customizing the study program to each student's particular weaknesses, this program filled in content gaps that regular instruction might not have remedied, as foundational math skills were already assumed in the grade students were. Three other interesting studies in this sub-category, which also intersect with the broader subsection of "Access to technology" are Berlinski and Busso (2017), Lehrer et al. (2019) and Blimpo et al. (2020). The latter two studies find that providing technology which also enabled improved instructional methods through features like lesson scripts (as in Blimpo et al., 2020) led to better test scores in Senegal and The Gambia respectively. An interesting feature of Blimpo et al. (2020) is that it consists of a very comprehensive treatment that improves access to technologies for teachers and students, but also supports targeted at improving instruction and student engagement. Therefore, the researchers cannot untangle the individual effects of each part of the treatment, and cannot ensure that all the gains were truly due to the portions targeted at improving actual classroom instruction.

Perhaps the most interesting case in this category, and certainly the exception in terms of effect size and direction, is Berlinski and Busso (2017). This study used 85 high schools across Costa Rica, targeting the seventh grade math curriculum, and providing a new non-EdTech instructional approach to encourage "active learning" in geometry. On top of this basic treatment, the study also tested the overlapping provision of different technologies such as interactive whiteboards, computer labs, and computers for each student across the different experimental arms. The authors find that no treatment arm had positive effects on learning, the intervention that simply had an instructional change to encourage active learning had *negative* effects in the order of -0.17 SD, and the treatment with active learning plus technology has negative effects in the order of -0.25 SD. Unlike in Adelman et al. (2015) in the previous section, the teacher take-up for this intervention was high, and it was implemented as expected. Instead, the authors attribute the negative results to worsened interactions between the teachers and their students, as evidenced by the negative effects on student discipline, and the teachers' feelings of worst control over the classroom management. This study acts as a cautionary tale warning against sudden instructional and curricular changes, particularly when these come with significant technological adjustments in the classroom.

The third sub-theme in this category is remote coaching and meetings, as best exemplified by Kotze et al. (2019) and its three-year follow up by Cilliers et al. (2020), and Wolf et al. (2018), in South Africa and Ghana respectively. These programs leverage technology to connect remotely with teachers and parents. In the case of Wolf et al. (2018), the authors integrate technology as a component in a broader treatment arm which intended to get parents more involved with the intervention. While the teacher training intervention was *less* effective when parents were involved, the bundled treatment does not allow the researchers to tease apart the effect of purely online meetings. On the other hand, Kotze et al. (2019) explicitly tested a virtual teacher training module versus an on-site training, in light of questions regarding the scalability of on-site coaching for teachers. The authors find that they both had similar positive effects, but the virtual training was slightly cheaper, and signified a less logistically-challenging task to scale than on-site coaching, in spite of the three year follow up of the study (Cilliers et al., 2020) showing diminishing returns to virtual coaching in the longer term. Finally, one important consideration for the rollout of virtual training is that teachers had to be provided with tablets, which even if it is cheaper than on-site training, may still require access to electricity.

In all, the current evidence points to the fact that the "improvements to instruction" category is a very promising area for the use of EdTech in developing countries. In fact, the median effect size among all studies reviewed was 0.28 SD, and the 75th percentile was 0.38 SD. Throughout most of the interventions reviewed here, the proper identification of contextual binding constraints when it comes to instruction seems to be a common thread. The design of the intervention around the issue at hand was key at improving learning levels, whether this constraint was teacher knowledge or effectiveness like in the case of Beg et al. (2019), or the scalability of teacher coaching systems, such as in Kotze et al. (2019) and Cilliers et al. (2020). A large portion of the studies focused on a model of partially replacing or supplementing some classroom instruction through technological tools like live broadcasted lessons, pre-recorded videos, T.V. shows, and audio recordings. This model of EdTech delivery acknowledges the diminishing returns from teacher instruction in contexts where teachers may not fully master the content they are expected to teach, or cannot deliver said content to the full range of achievement levels within their classrooms.

Having already discussed the promising role for this type of interventions, it is important to also mention that none of the papers included here speak to whether EdTech can fully replace classroom instruction. This is a crucial question, especially if schools are not only thought of places to build academic skills, but also a place of socioemotional and psychological development. Furthermore, given the key role of locally-identified constraints in the effectiveness of this type of intervention, none of the papers reviewed seem to suggest that *all* EdTech interventions which address shortfalls in instruction through complementation or replacement of time work. In fact, Berlinski and Busso (2017) serves as a stark reminder of an intervention which had negative effects, and were only aggravated by the use of technology. While the current literature empirically explores cases of EdTech ameliorating learning through improvements in instruction, there still needs to be more research on what areas of the classroom experience are riper for this type of intervention. In other words, if there is at least one study with negative effects, and other studies with different magnitudes for their positive effects, there is a possibility that EdTech can play different roles when it comes to substituting or complementing instruction. Therefore, future areas of research could explore whether EdTech is more effective at replacing actual instruction or at reinforcing instruction through tailored exercises after an actual teacher lecture. Similarly, future research could inform what teacher and school characteristics are more predictive of effective classroom instruction replacement by EdTech components.

EdTech can also be leveraged to incorporate other changes to instructional methods. For instance, scripts which the provide scaffolded lesson plans to teachers have been a part of successful interventions in several developing countries (Piper et al., 2018). Although scripts do not necessarily have to be delivered through a technological device, education providers such as Bridge International Academies already leverage handheld devices connected to the internet to routinely deliver structured lessons at-scale to all of their teachers across several developing countries. While scripts have been part of promising interventions that have raised literacy outcomes for children, no impact evaluations of purely teacher scripts were located for this review, much less as delivered by electronic devices. Similarly, there are no publicly available impact evaluations of different features in teacher scripts and how these affect the quality of instruction, in spite of the valuable descriptive analyses in Piper et al. (2018) and Piper and Evans (2020).

d. Self-led learning

The success and cost-effectiveness from the evaluation of the MindSpark software in Muralidharan et al. (2019) sparked great interest in technological interventions which allow students to learn at their own pace, and at their own level. EdTech interventions that enable students to learn at a fitting pace with minimal external support seem particularly enticing, especially in contexts where regular classroom instruction may not be as effective, and there are important resource constraints in terms of teacher and tutor time to ensure that all children make similar progress. Furthermore, interventions that target “self-led learning” have been one of the main areas of EdTech research, accounting for a third of all core studies identified by this review, and dating back to at least 2003 (Rosas et al. in Chile). While it is difficult to draw a sharp distinction between "self-led learning" and "improvements to instruction", the general spirit of "self-led learning" is precisely interventions that students can do mostly on their own without intensive supervision, and do not necessarily intend to improve the overall classroom instruction as a mechanism to achieve higher learning, but rather to deliver content directly to students. Similarly, unlike in the "access to technology" category, most of the interventions in this category did not provide students with the hardware or the devices to engage with the intervention and instead, most self-led activities were software-oriented. While it would be possible to implement an intervention which merges "access to technology" and "self-led learning" at an individual level (e.g. through the provision of a handheld device with appropriate self-led software installed), most of the interventions in this category leveraged technology at the school-level. By targeting communal sharing of the hardware to implement self-led interventions, the marginal costs spread out further than initiatives like OLPC, as it allows several students to use the same hardware during a school year, and then for several cohorts to keep using until it fully depreciates.

Studies in this category aim to address important policy challenges shared by many developing countries. Recent decades have seen large increases in enrollment rates across the world, as the number of pupils in primary school increased by 350 million between 1970 and 2018 (World Bank[17]). This overall positive trend poses the distinct challenge of heightened pressure on the already strained school resources and personnel. While the number of in-school children in low-income countries rapidly increased after 2000, the pupil-teacher ratio remained largely the same —three times larger than that of high-income countries— displaying the system's capacity to barely catch up in terms of teacher recruitment. As Duflo et al. (2011) point out, in practice, the fact that on average teachers have to deal with 40 pupils at the same time translates into a lack of bandwidth to cater to all students in their classes, and the wide distribution of achievement levels that comes with these students. This situation is worsened by external political incentives to focus on high-performers and to teach to the top students within classes (Glewwe et al., 2009), and by "overambitious and fast-moving curricula" which move faster, and aim higher than the realistic amount of material which could be taught within the contextual constrains (Pritchett and Beatty, 2015). Ultimately, these pressures accentuate the increased within-country, within-school, and

[17] World Bank Development Indicators: Primary education, pupils.

within-class inequalities that widened after these enrollment increases. Therefore, if EdTech products can directly customize "instruction" to each student's level, or allow teachers to focus on specific groups of students while other students are engaging with appropriate practice exercises on technological platforms, EdTech could be a very valuable tool to narrow learning and instructional inequalities.

Interestingly, the majority of all studies in this section had at least one treatment arm with positive effects on learning. In fact, the median effect size in this category is 0.29 SD, and the 75th percentile is 0.46 SD. Therefore, the bulk of the evidence in this section does not revolve around whether there is a model of self-led learning which works, but rather around how different design features of self-led learning interventions moderate the effects that these have on learning outcomes. Two important exception of this are Büchel et al. (2020) and Ma et al. (2020), which instead of testing a different feature of an EdTech intervention, evaluate an EdTech intervention in relation to a comparable "pencil-and-paper" treatment. In the case of Ma et al. (2020), the authors highlight that EdTech interventions, particularly those in this category, tend to happen after school. Therefore, there is a question about whether any learning gains observed are due to the EdTech portion of the intervention, or rather due to the additional practice time. The authors find that for their particular treatment, the EdTech treatment branch is no more effective than the non-EdTech arm, suggesting that part of the success of interventions in this category may be because it offers students additional practice time. On the other hand, the authors of Büchel et al. (2020) test whether students assigned to computer-assisted learning (CAL) fare better than those in a traditional teaching environment during a weekly, 90-minute intervention, finding that CAL is indeed more effective than traditional teaching in their context. The contrast between these two interventions may lie in the contextual counterfactual for each. While the Ma et al. (2020) study was conducted in China, the Büchel et al. (2020) study was conducted in El Salvador, a country with a lower development level, and weaker state capacity that may translate into a poorer traditional classroom experience. Hence, this difference highlights the importance of clearly understanding the contextual constraint that an EdTech product would address, and the resources that it would be displacing if implemented. Having said this, there may be features inherent to self-led EdTech interventions that can still make EdTech desirable over non-EdTech interventions, or business-as-usual teaching. For instance, EdTech software has the capacity to hold a very large number of questions, with a wide range of difficulty, and with minimum setup and external support, allowing for greater scalability and extended exposure to each intervention.

One of the first design features that the literature touches upon is the difference between "computer-assisted instruction" (CAI) and "computer-assisted learning" (CAL). Although some authors use the terms interchangeably, the clearest distinction is drawn by Bai et al. (2016). This study defines CAL as not necessarily integrated into the teachers' instruction and curriculum, whereas CAI is. In fact, Bai et al. (2016) test this distinction explicitly in their experimental design, by comparing CAI and CAL treatment arms to a pure control group, finding suggestive evidence that CAI was more effective than CAL at raising English test scores. More broadly, other papers tested one or the other model without explicitly defining their intervention as CAL or CAI. Linden (2008) is an informative paper in this regard, particularly as it also studies the properties of EdTech as supplements or complements to math instruction in Gujarat, India. Linden (2008) compares a computer-led intervention implemented as an in-school program ("substitute" of in-class instruction), or out-of-school addition ("complement" of in-class instruction) on second and third graders. The author finds that the intervention had negative effects as a supplement of instruction, but the intervention had positive effects in the order of 0.3 SD when it was used as a complement to reinforce instruction, effectively being used as CAI. Other interventions such as He et al. (2008) were leaning more towards the CAL side, as it was focused on self-exploration of topics within a specialized device, also yielding positive effects. In this sense, the difference between these two approaches is not necessarily along the margin of whether one is strictly better than the other, but which one is better suited for the task at hand. Work such as Bai et al. (2008), Lai et al. (2013, 2015, 2016) or Mo et al. (2014a, 2014b) highlights the virtue of CAI to act as a complement to in-class instruction and content, while work such as Linden (2008), Bettinger et al. (2020), Carrillo et al. (2011), Chong et al. (2020), or Rosas et al. (2002) displays the potential of CAL to reinforce concepts that do not precisely mimic the students' curriculum at any specific point in time. For instance, Chong et al. (2020) targets sex education for Colombian teenagers, and stands as a valuable example of a case when CAL may be more effective than CAI, especially if the content delivered in class would either be poorly communicated at school or not taught at all.

Another important design feature that has captured little research attention across the papers in the set of core studies is the incentives provided to students to engage with EdTech products. Hirshleifer (2016) is the only study included in this review which explicitly evaluates two different incentive schemes. Specifically, the author studies whether rewarding “inputs” or “effort” to engage with an EdTech product is more effective than rewarding “outputs” or the actual score obtained on the EdTech activity. Hirshleifer (2016) finds that for their specific intervention, rewarding inputs is more than twice as effective as rewarding outputs, although both modalities of rewards yield important learning gains. However, this paper only deals with one type of small reward with a maximum value of USD 2.65 per child, and does not test different types of rewards such as social recognition, symbolic gestures of teacher appreciation, or the potential to earn a significantly larger prize. Similarly, work such as Araya et al. (2019) or Rosas et al. (2002) recognize the potential for gamification in driving engagement with an EdTech product. In a qualitative analysis into potential mechanisms for their lack of significant results, De Hoop et al. (2020b) find that some characteristics of their product seemed repetitive, and led to boredom for the students using the software they evaluate. Therefore, including features that touch upon “gamification” to drive engagement with EdTech products could potentially be an even more cost-effective incentive. Still, so far none of the studies included in this review explicitly tests the sole effect of features like gamification on the effectiveness of an EdTech product.

A key component of some EdTech products which has not been evaluated in isolation is the optimal degree of adaptability, i.e. the potential for the product to auto-identify and adjust the level of difficulty to a student’s specific achievement level. This particular feature has been a core component of very successful interventions such as Banerjee et al. (2007), Muralidharan et al. (2019), Ito et al. (2019), and Carrillo et al. (2011). Given the wide variation in achievement distributions within classrooms in many developing countries, this feature is one of the most enticing characteristics of EdTech, and it is hard to imagine that it would be anything but beneficial for each student’s learning path. Therefore, the key empirical question around adaptability is not whether it works or not, but rather what the optimal degree of adaptability is. This is relevant since there are certainly higher development costs to creating deeper question banks with different difficulty levels, and to the ideation of more sophisticated algorithms to precisely place students within the performance bin that the EdTech product would target. In spite of the potential relevance for policymakers and product developers, no paper in the current set of core studies directly addresses this question in a self-led learning intervention.

The final feature discussed in this review[18] for which little evidence currently exists is the optimal dosage for an intervention. All interventions in this category have different lengths for their study sessions, and different number of weeks during which students were a part of the intervention. However, only Bettinger et al. (2020) explicitly tests the effect of different dosages of an EdTech intervention. The authors find that while the treatment does have positive effects on learning, the full doubling of the dosage does not have statistically different effects from the baseline intervention. This finding agrees with the null correlation found between dosage and effect size across different studies in Sampson et al. (2019). Understanding this relationship is crucial when deciding not only whether EdTech should be a complement or a supplement to education, but also to what degree it should be implemented as either. Furthermore, dosage is an important feature given the nature of *self-led* interventions, where the learner must have some autonomy, and the ability to understand how the product works. An intervention with a long dosage period, but which low-performing students struggle to engage with, is likely to have heterogenous effects across the full distribution of achievement, ultimately benefiting stronger students and widening within-class and within school inequality. In fact, Carrillo et al. (2011) and He et al. (2008) observe that higher-performing students perform better their self-paced EdTech interventions. Therefore, the suitability of the treatment for the specific context, adaptability for different learning levels, and crucially, the right dosage for everyone's needs are pivotal elements to ensure that self-led EdTech interventions can cater and boost educational outcomes for all students.

V. Lessons learned and frontiers of the current evidence

The current review provides a comprehensive compilation of rigorously evaluated EdTech interventions in developing countries. By thematically grouping all 81 core studies, broader lessons can be drawn for future research and implementation of EdTech interventions, as synthesized in Table 1. Among the four categories, the most promising areas in raising learning outcomes in absolute terms were "improvements to instruction" and "self-led learning." The overall success of these two areas rested on the customization of the EdTech solution to the constraint at hand. The studies included in "improvements to instruction" addressed more

[18] Note that this is not a comprehensive list of potential features to be studied and/or included in an EdTech product. Sampson et al. (2019) mentions other potential features which an EdTech product could include, such as the inclusion of different components like "explanatory videos", "practice exercises", "problem solutions", "assessments", "quizzes/stories", "simulations", "flash cards", among others.

systematic constraints such as weak teacher quality in certain remote areas or teaching coaching through scalable, virtual means. The "self-led learning" studies focused more on a direct link connecting students to learning through technology like apps or educational software. At the same time, "technology-enabled behavioral interventions" also seems to be particularly effective at solving problems of informational-asymmetries, accountability, and enforcement of duties, while also being particularly cost-effective and prone to scalability. The studies under "access to technology" did not show a pattern of raising learning, only students' acquaintance with technology. However, interventions that facilitate access to technology are a first and necessary step to implement other EdTech solutions like educational software, especially in many remote and deprived areas. Most importantly, there is a need for researchers and policymakers to move away from a dogmatic adherence to one of the four areas, and to embrace the fact that all four areas can act as mutually complementary in addressing deficiencies within educational systems.

Table 1: summary of EdTech interventions in developing countries by thematic area

	Access to technology	Technology-enabled behavioral interventions	Improvements to instruction	Self-led learning
Intended policy targets	Low penetration of technologies capable of hosting educational features; low familiarity with digital skills.	Informational barriers; behavioral inconsistencies; lack of accountability; alignment of incentives.	Gaps in teacher knowledge; difficulties to recruit teachers in remote areas; scalability of student and teacher training programs.	Reinforcement of material and practice problems; addressing student-specific gaps in skills; adjusting the pace and level of instruction.
Effectiveness	Very low for academic learning, medium for increases in familiarity with digital tools.	Low to medium for learning outcomes.	Consistently medium to large effects for learning outcomes.	Among the software evaluated, consistently medium to large effects for learning outcomes.
Cost-effectiveness	Extremely low. Poor effectiveness coupled with high marginal costs. As a result, expensive to scale.	Very high, particularly due to the very low marginal costs of most interventions. Very high potential for scalability.	High, as fixed costs of product development tend to be higher than marginal costs.	High, as interventions are often implemented in community- or school-level computer labs so the same hardware/software can reach many students.
Best uses	Increase familiarity with technology; or as a platform to implement other types of EdTech interventions.	Improve enforcement of policies; provide information at scale.	Deliver high-quality education to areas where this is a serious constraint.	Complement classroom instruction; reinforce lessons; fill in content gaps.
Potential pitfalls and challenges	Leakage and misuse of equipment; crowding out of time better spent in other educational activities.	Interventions require particularly deep contextual knowledge about behaviors that can be shaped through relatively low-touch interventions.	A sudden change in technology that does not directly address a pressing problem may hinder instruction and lead to negative effects in learning.	Software needs to be developed for more contexts; languages, and subjects. Reliance on self-guidance may benefit high achievers more; increasing within-class inequality.
Examples of interventions	One-laptop-per-child (OLPC) (Barrera-Osorio and Linden, 2009; Cristia et al., 2017); provision of handheld devices (Habyarimana and Sabarwal, 2018; Mensch and Haberland, 2018)	Keeping parents up to date on student performance and attendance via SMS (Berlinski et al., 2016); monitoring teacher attendance through cameras linked to pay incentives (Gaduh et al., 2020)	Broadcasting of live instruction remotely (Johnston and Ksoll, 2017); pre-recorded video and audio lessons to supplement classroom instruction (Beg et al., 2019; Näslund-Hadley et al., 2014)	Software (typically self-adaptive) to practice language and math skills (Muralidharan et al., 2019; Linden, 2008; Carrillo et al.; 2011; Araya et al., 2019); Online classes (Chong et al., 2020).

Another important lesson that emerged from the four thematic areas is the importance for an EdTech intervention to be thoughtfully designed around a carefully identified contextual issue. To illustrate this point, one can look at the way in which Beg et al. (2019) identify clear contextual constraints, and then designed the intervention around these. The constraint in their case was the unavailability of qualified teachers and teacher absenteeism. They hypothesize about appropriate and scalable technological approaches to address these issues with contextually-grounded theories of change that involve the provision of short videos with academic content in math and science. This design then led to large and cost-effective gains in learning, and to some extent increased teacher effort. Importantly for scalability considerations, this EdTech program was implemented through the local government. Contrarily, this intervention stands in sharp contrast to Angrist and Lavy (2002), or even the OLPC interventions, which attempted to address a more nebulous issue of access to computers without a clear theoretical, causal path between owning a computer to improved school performance. In the extreme case of Angrist and Lavy (2002), a well-intentioned and expensive intervention ended up even yielding negative results in learning.

The quality of implementation and take-up from relevant stakeholders also stand as pivotal components to understanding the success or failure of an intervention, especially with limitations on state capacity. However, quality of implementation does not seem to replace a well-designed program. In other words, while quality of implementation could make or break a project that may be indeed appropriate to address certain issues if properly implemented, such as in Adelman et al. (2015), a successful implementation and take-up does not guarantee gains in educational outcomes. As an illustration of this point, Berlinski and Busso (2017) report high take-up of their treatment, and no issues with implementation are reported. However, the intervention also led to negative effects on learning, which was hampered by the inclusion of technology into a pedagogical change. While an initial reaction to this major point about quality of implementation may be to motivate implementers of the study to exert exceptional effort and resources to ensure that the intervention goes precisely as planned, the end goal for most of these interventions is to test whether they have a potential for scalability. In many cases, the difficulty of maintaining a high implementation quality tends to get larger with the size of the intervention. Therefore, a lesson that emerges from this review, and from other work like Niehaus and Muralidharan (2016) for that matter, is to give preference to intervention designs with relatively few touchpoints between the delivery of treatment and the target population, so that if and when the intervention is scaled, it can adhere to similar implementation standards as in the evaluation phase.

Relatedly, the question of scalability also emerges as an important issue when it comes to EdTech interventions. For instance, an interesting feature for EdTech interventions is the interplay between fixed and marginal costs[19]. Depending on the type of intervention, there could be serious trade-offs between the two types of costs that could significantly affect scalability and economies of scale in expanding treatment to other individuals. Two opposite examples are the OLPC studies (Barrera-Osorio and Linden, 2009; Beuermann et al., 2015; Cristia et al., 2010, 2017; de Melo et al., 2014; Meza-Cordero, 2017) versus the "Sesame Street" studies (Borzekowski, 2018; Borzekowski, 2010; Borzekowski et al., 2019a; Borzekowski et al., 2019b). The nature of OLPC policies is that the cost of adding an additional child is exactly the cost of a laptop. There may be some economies of scale through lower prices when buying computers in bulk, but the marginal cost is still considerably higher than any fixed costs per student associated with running the program. Contrarily, the cost of "Sesame Street"-type interventions is mostly focused around the fixed-costs of developing, producing, and distributing the T.V. episodes. However, the marginal cost of another student watching the show is effectively zero. Unsurprisingly, most of the studies reviewed here lie somewhere in between these two extremes, and their position along this spectrum also depends heavily on the area of the review. For instance, interventions within the "access to technology" category tend to skew towards higher marginal costs, and interventions within the "improvements to instruction" tend to skew towards higher fixed costs. This distinction is crucial to welfare analyses of EdTech interventions, as interventions with low marginal costs and positive effects, as small as they may be, stand to achieve efficiency improvements by enrolling more children, while interventions with high marginal costs must consider more carefully whether the marginal benefit to the infra-marginal student will indeed justify the relatively higher costs.

Another potential consideration for the scalability of EdTech products is the trade-off between the economies of scale of product development, and the tailoring of a product to the local context. In other words, the smaller the market an intervention intends to target, the costlier the tailoring of the intervention would be. For instance, an EdTech solution focusing on early language development in a country with many regional languages would either need to develop a different

[19] For an excellent review of the advantages, and necessary conditions for the successful scalability of interventions in developing countries, see Niehaus and Muralidharan, 2016.

version for each regional language, or focus on the main national and/or colonial language, which may also have equity implications. A similar pattern occurs across different grades: while most early curricula in most countries focuses, in one way or the other, on the development of foundational literacy and numeracy skills, the contents of curricula grow increasingly different across countries with grade progression. Therefore, an app focusing on early skills may have a larger potential market than one focusing on a niche curricular feature, such as pre-colonial Nigerian history, which may be present in Nigeria's curriculum but not Ghana's.

Given the inherent limitations, costs, and barriers to entry that EdTech interventions may face, it is also important to note that from the core set of studies, it is not clear whether EdTech interventions *always* achieve higher learning gains and are *always* more cost-effective, compared to other non-EdTech interventions in developing countries. In this sense, the question that policymakers and researchers face when evaluating an EdTech intervention should not be whether this technological approach could address a problem in the educational system, but rather whether it would be the most effective and cost-effective way to do so. Indeed, there are examples of non-EdTech interventions in developing countries that have been equally as successful at raising learning standards as the most promising EdTech solutions, such as "Teach at the Right Level" (Banerjee et al., 2016) or the combination of other fruitful approaches such as scripting and after-school remediation lessons (Eble et al., 2019). Besides the cost and ease of implementation and scalability, the decision to implement an EdTech intervention versus an equally well-designed non-EdTech solution should come down to whether the intervention could benefit from the comparative advantages offered by EdTech, such as the potential for high levels of customization of practice exercises or remote engagement.

Among the set of broader questions that remain on the frontier of EdTech research are those involving "general equilibrium" effects after the rollout of an EdTech intervention. Very little is known about the system-level, medium- and long-term effects on teacher attitudes, effort, and behavior following an EdTech intervention. One can imagine a context where teachers quickly adapt the technology to their daily routine and set of tools, as it becomes an integral part of education. Conversely, there could also be a scenario in which the take-up of technology only happens during a brief period of excitement or monitoring, and the use is then gradually discontinued. Similarly, one can imagine teachers feeling more motivated about new technology lifting some of their instructional burden and hence putting more effort into the time that they actually teach, or on the contrary, teachers relying on EdTech as a substitute of instruction to maintain or increase their absenteeism rates. Questions of this nature can be asked at the school-level and even at the system-level, where it is unclear whether EdTech can crowd out resources of other important educational inputs, or will instead boost the effectiveness of other complementary investments. Similarly, little is known about EdTech's potential to increase inequality at a larger scale, if effective EdTech interventions are also not available for disadvantaged groups. While it is too soon to point to tangible data (at least from developing countries), the school closures induced by the COVID-19 pandemic are a stark example of how the availability of EdTech at home could have minimized learning losses heterogeneously for different socioeconomic group. Finally, susceptibility of EdTech interventions to political and investment cycles is an important, yet understudied topic[20]. Conditional on finding a set of interventions that raise educational outcomes in a specific context, the continuity of these programs by future education leaders and policymakers is just as crucial as the finding that the intervention is an effective one.

The breadth in the EdTech literature, in terms of type of intervention and context, is greater than the current depth of it, both in terms of replication of studies in different contexts, and multiple angles to similar research questions. As EdTech keeps growing throughout different developing countries, and policymakers face more options to address the particular challenges in their respective contexts, the body of knowledge in various aspects of when, where, and for whom EdTech interventions work must also grow. Addressing critical questions of scalability, external translation of results, preparedness for EdTech interventions within and between countries, and the particular shortcomings of educational systems in developing countries where EdTech can be most effective will be of paramount importance to keep up with an evidence-based agenda in pursuit of improved educational and welfare outcomes for people in the developing world.

[20] For informative case studies on how South Korea, Estonia, and Uruguay have integrated ICT into their educational system at-scale, see Díaz et al., 2020.

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