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Computer-assisted instruction tools: A model to guide use in low- and middle-income countries

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ABSTRACT

Learning outcomes in low- and lower-middle-income countries (LMICs) require significant improvement. With traditional reform efforts taking many years to realise results, education practitioners in LMICs are searching for innovative ways to rapidly strengthen learning outcomes. One tool showing promise is computer-assisted instruction (CAI). While a growing number of studies document CAI's positive impacts on learning outcomes, others have found nil or negative effects. Research has yet to identify why these differences occur, and, most importantly, which factors must be in place to ensure that CAI contributes to improving learning outcomes. The aim of our research was to fill this gap in the research by developing a model highlighting those factors influencing the results of CAI interventions. Adopting a realist-informed methodology, we analysed 21 resources shared by 13 experts from around the world. We used the results of this analysis to develop a model that outlines key trends that facilitate and/or impede the deployment of CAI tools in LMICs. We find that key factors that should be considered when designing CAI interventions include the operating environment; stakeholder engagement; infrastructure; technological trust; CAI tool design; content curation/creation; student engagement; classroom integration; teacher capacity; student capacity; and data collection and use. This model highlights both these individual elements as well as noting how these elements interact. The model provides a foundation that can guide future research in this under-examined area.

INTRODUCTION

Sustainable Development Goal 4 - ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all – is one of 17 goals established by the United Nations (UN) and endorsed by all UN member states in 2015. This goal is unlikely to be achieved. While school enrolment and attendance are improving in low- and lower-middle-income economy countries (LMICs), millions of children in these countries are not learning.[1] These students are not being equipped with the basic skills and competencies required to live happy, health and economically stable lives (UNESCO-UIS, 2016).

Teacher skills and competencies, or a lack thereof, is one of the most significant factors preventing children in LMICs from acquiring basic skills (UNESCO, 2021). There are three main reasons for this. First, not enough teachers are in place to meet student need. Nearly 25 million teachers are required by 2030 to ensure that every child in the world receives primary education (UNESCO-UIS, 2016). Second, teachers are not adequately trained. UNESCO (2014) notes that in a third of countries collecting data, 75 percent of teachers were not trained in line with national standards. These teachers lack an adequate foundation of pedagogical skills and content knowledge to provide students with high quality learning experiences. Third, systems for professional development are weak, inconsistently implemented, and focus on theory rather than practice

[1] Low-income countries are those with a gross national income per capita of less than $1,025. Lower middle-income countries are those with a GNI per capita of between $1,026 and $3,995. These categories are used by the World Bank to identify economies eligible for additional funding and support for development activities. The term LMIC is used in this paper to refer to both low- and lower-middle-income countries.

(World Bank, 2018). While enhancing teaching quality in LMICs is a priority, training teachers is difficult and time-consuming, and such efforts typically take years to significantly improve learning outcomes. Students currently in schools in LMICs need a higher quality of education immediately; they cannot afford to wait years for better teachers. An alternative to long-term teacher development is required now.

A potential alternative that may positively influence student learning outcomes is computer-assisted instruction (CAI). The definition of CAI is used in various ways in both academic literature and practitioner documents. For example, in their recent rapid evidence review of personalised and adaptive learning Major & Francis (2020) note the overlap in terminology that exists across computer-assisted learning, computer-aided learning, computer-aided instruction, intelligent tutoring systems and cognitive tutoring systems. In our research CAI refers to software that delivers a personalized, interactive, adaptive learning experience to students (Bulman & Fairlie, 2015; Lipson & Smith, 2013). Our definition positions CAI as a software that is device agnostic and can be used online or offline. The software can use various mediums (video, audio, games, quizzes.) and can collect data from student interactions (such as, assessment results and software interactions) which can be used to select which materials should be delivered to the student. We focus on the integration of CAI into classrooms to complement, rather than replace, traditional teacher-focused approaches to content delivery. The CAI tools can be used to provide higher quality education experiences to students now, in parallel to the longer-term teacher training initiatives. Finally, in this paper we discuss both CAI tools and CAI interventions. When we discuss CAI tools, we refer to the CAI software, including the content contained within it. When we discuss the CAI intervention, we are referring to the design of the broader program which supports the roll-out of the CAI tool. This includes, for example, teacher training and communication.

While CAI shows potential, resources from various contexts highlight that the impact of CAI on learning outcomes varies significantly. For example, Power, Gater, Grant and Winters's (2014) Educational Technology Topic Guide, which investigates the use of EdTech in LMICs, found instances of CAI both positively and negatively impacting learning outcomes. While the studies in this review highlight the variable results emerging from CAI research, they do not explore the factors which contribute to these outcomes. Other discrete studies assessing the impact of CAI interventions also neglect to explore these factors (Owusu, Monney, Appiah, & Wilmot, 2010; Yunusa, Umar, & Bervell, 2019). The lack of insight into these factors reflects research into CAI use generally. Empirical papers often demonstrate how CAI impacts learning outcomes but neglect to analyse the factors which influence these results. Additionally, the majority of the literature that does exist focus on the use of CAI in middle- and higher-income economies.

While research in developed countries is more advanced, this has been deliberately excluded from this research as deploying CAI tools in LMICs means confronting a unique set of context-related challenges such as lower levels of connectivity and the aforementioned low teacher capacity. The factors influencing the outcomes of CAI interventions are likely to vary significantly according to these contextual elements. To be able to harness the potential of CAI in LMICs, greater insight into which factors contribute to either positive or negative results is needed. With this in mind, we pursued two research questions:

1. In cases where CAI generates positive outcomes, which factors contribute to these results?
2. In cases where CAI generates nil or negative outcomes, which factors contribute to these results?

Based on our research into these questions, this paper presents a model identifying the factors impacting CAI effectiveness in LMICs. The model has been developed using a realist-informed approach which included requesting 13 experts from relevant fields to share the more pertinent

resources (a total of 21 were shared). The paper contributes to the rapidly emerging evidence base examining the potential of EdTech more broadly, and CAI specifically, with a specific focus on supporting improvements in learning in LMICs. Specifically, we envisage that this model will provide a framework that can be followed by researchers interested in conducting either a more detailed literature synthesis or empirical research.

METHODOLOGY

A realist approach to theory building

Traditionally, experimental research designs have been considered the gold standard of research approaches. However, experiments are limited as they do not "capture the complex nature of interventions whose outcomes, by definition, depend on the context in which they are implemented" (Robert, Ridde, Marchal, & Fournier, 2012, p.5). As our research questions go beyond identifying whether CAIs work, and instead focuses on the when, why and how of deployment, a traditional systematic review approach is unsuitable. Instead, a realist-informed approach was adopted.

Realist research is an explanatory quest that generates and iteratively refines theory (Pawson & Tilley, 1997). Realist researchers build or refine program theories to explain complex phenomena. These theories aim to identify what about an intervention "works, for whom, in what circumstances, in what respects and why" (Pawson, 2006, p. 94; Wong, Westhorp, Greenhalgh, Pawson, & Buckingham, 2013). Due to the complexities involved in going beyond whether some works examine the reason behind result, realist approaches actually endorse the use of many and varied data sources – "grey literature[2], policy documentation, interviews with key programme architects, and formal social science theory" – to gather insights (Pawson, 2013, p. 3). We selected a realist-informed approach for this research for a number of reasons. First, because realist approaches are designed to generate more detailed insights into which factors influence the success or otherwise of outcomes, rather than just focusing on the outcomes themselves. Second, the use of CAI in LMICs faces a unique set of contexts that will influence the success of these interventions. While there is an existing, albeit limited, research base into these factors in higher income countries, the lack of research in LMICS means that our research needed to go beyond formal academic papers to include grey literature.

The realist paradigm is relatively new and comprises research methodologies that continue to evolve. Emerging in 1997, the paradigm continues to be refined through four mechanisms. First, Pawson and Tilley, the realist paradigm's original authors, have continued to refine the approach (Pawson, 2006, 2012, 2013b; Pawson & Tilley, 2004, 2012). Second, a new wave of authors including Geoff Wong, Trisha Greenhalgh (both University of Oxford) and Gill Westhorp (Charles Darwin University) continue to explore/refine the methodology. Third, through the Realist And Meta-narrative Evidence Syntheses: Evolving Standards (RAMESES) project, publication/reporting and quality standards have been created to guide realist research (Wong et al., 2017, 2013). Fourth, a range of scholars are using the realist paradigm in their research, leading to new iterations of the research approaches. This ongoing refinement of the methodology means that at this point in time, there is no single agreed prescriptive approach to conducting realist research. Rather, there are some key underpinning principles that inform the different stages of the realist research approach.

In our research, the realist approach informed how we located, analysed and synthesised studies to develop our initial theory. The methodology for this was informed by Pawson, Greenhalgh, Harvey and Walshe (2004). In line with the realist approach, we began with a process of

[2] Materials and research produced by organizations outside of the traditional commercial or academic publishing and distribution channels

"conceptual sharpening" (Pawson et al, 2004, p.13). This was followed by a two-stage process to "search for relevant evidence, refining inclusion criteria in light of the emerging data" (ibid, p.13).

While we followed the foundational steps recommended by Pawson, Greenhalgh, Harvey and Walshe (2004), we also made some important adjustments to this approach. There are few resources focusing explicitly on CAI use in LMICs, and even less that examine the factors that influenced the outcomes of these studies. Consequently, we decided that we would not develop a set of context-mechanism-outcome configurations, an approach often used in realist research. We excluded this because the literature did not provide a clear enough differentiation between the different factors and how they influenced the outcomes. Instead, we have put forward a model which highlights the factors that may influence the success or otherwise of CAI interventions in LMICs.

Conceptual Sharpening

Conceptual sharpening is used at the beginning of realist research to "define and refine precisely the question to be pursued" (Pawson et al., 2004, p.13). In our research, conceptual sharpening involved attempting to gain insight into the use of CAI in LMICS. Noting the cutting-edge nature of CAI, we sought up-to-date guidance from experts in the field. This aligns with Saul, Willis, Bitz, & Best (2013, p. 3), who suggest beginning realist research by engaging with "knowledge users and content experts". We asked 13 experts with experience in designing, implementing or researching EdTech in LMICs to share their insights into the use of CAI in LMICs and resources they thought could inform our research. In line with the realist research philosophy of quickly gaining insights from a diverse set of resources, we reached out to various contacts, chosen from our networks, from diverse professions to bring unique insights. All the experts we contacted had at least 8 years' experience working with EdTech. While we generally selected people, who had worked in LMICS, we included two experts who were without experience in LMICs as they brought a different perspective to our sharpening process. Table 1 contains an overview of those consulted, while further details on each expert are shown in Table 2.

Table 1: *Experts consulted to refine research purpose*

	Profession	**Experience in LMICs?**
Expert 1	Global EdTech lead, international development agency	Yes
Expert 2	Senior education advisor for UN Agency	Yes
Expert 3	Director of research for global EdTech advocacy body	Yes
Expert 4	Academic	Yes
Expert 5	Academic	Yes
Expert 6	Global education research lead for international aid agency	Yes
Expert 7	Secondary school teacher	Yes
Expert 8	Regional education lead, international NGO	Yes
Expert 9	EdTech entrepreneur	Yes
Expert 10	Program analyst at innovation in education financing agency	Yes
Expert 11	Academic	Yes
Expert 12	EdTech software developer	No
Expert 13	CEO of EdTech advocacy body	No

Table 2: *Details of experts consulted*

	Organisation type	Role	Location	Experience in LMICs?	Country experiences	Years' working w/ EdTech	Gender
Expert 1	Development agency	Global EdTech lead	United States	Yes	20+ LMIC countries.	24	Male
Expert 2	Development agency	Senior education advisor	Kenya	Yes	Kenya, Botswana, India, United Kingdom	8	Male
Expert 3	EdTech research and implementation organisation	Director	United Kingdom	Yes	United Kingdom, Sierra Leone, Germany	16	Male
Expert 4	University	Academic	Australia	Yes	10+ LMIC countries.	27	Male
Expert 5	Development agency	Academic	United Kingdom	Yes	United Kingdom, Senegal, South Africa, Kenya.	8	Female
Expert 6	Development agency	Global education research lead	Denmark	Yes	Denmark, United Kingdom, Bangladesh, Malawi.	9	Female
Expert 7	School	ICT integration lead	Qatar	Yes	Qatar, Bangladesh, Australia	10	Male
Expert 8	Development agency	Regional education lead	Kenya	Yes	Kenya, United States, Pakistan, Uganda, Ethiopia, .	11	Male
Expert 9	Private sector	EdTech entrepreneur	Kenya	Yes	Kenya, Uganda, Somalia, Mauritius, United Kingdom.	8	Male
Expert 10	Development agency	EdTech program analyst	United States	Yes	United States, Turkey, Kenya, Mozambique.	9	Female
Expert 11	University	Academic	United States	Yes	United States, Singapore, Tanzania	13	Male
Expert 12	Private sector	EdTech software developer	Australia	No	Australia, United States.	14	Male
Expert 13	EdTech advocacy	CEO of EdTech advocacy body	Australia	No	Australia.	14	Female

We requested that the experts share resources that were specifically relevant to the use of either CAI specifically or EdTech generally in LMICs. The experts shared 18 resources with us. Of these,

seven were empirical studies, with the remainder a mix of reports, reviews, blogs and other types of publications. The resources covered a range of different topic areas. Some were focused on CAI specifically, others touched on CAI as part of broader discussions, while some did not mention CAI at all but included insight on the implementation of EdTech interventions in LMICs generally. Table 3 contains a summary of the resources received.

Table 3: *Resources received from experts*

Author(s)	Year	Title	Location	Type
Brusilovsky & Peylo	2003	Adaptive and Intelligent Web-based Educational Systems	N/A	Conceptual paper
Carlson	2013	Using Technology to Deliver Educational Services to Children and Youth in Environments Affected by Crisis And/Or Conflict	South Sudan, Somalia, India	Report
Carlson	2019	Here's Why Teachers Adopt New Tech — and Why They Don't	N/A	Blog
Chris	2015	Barriers Hindering Implementation, Innovation and Adoption of ICT in Primary Schools in Kenya	Kenya	Empirical study
Escueta et al.	2017	Education Technology: An Evidence-Based Review	Developed countries	Review
Hsu et al.	2013	Trends of educational technology research: More than a decade of international research in six SSCI-indexed refereed journals. Educational Technology Research and Development	N/A	Review
Istance, D., & Paniagua, A.	2019	Learning to Leapfrog: Innovative Pedagogies to Transform Education.	Developing countries	Report
Masingila et al.	2018	From Implementation to Efficacy: Factors Affecting Kenyan Secondary Teachers' Technology Integration	Kenya	Empirical study
McEwan	2015	Improving Learning in Primary Schools of Developing Countries: A Meta-Analysis of Randomized Experiments. Review of Educational Research	Developing countries	Meta-analysis
Muralidharan et al.	2019	Disrupting Education? Experimental Evidence on Technology-Aided Instruction in India. American Economic Review	India	Empirical study
Owusu et al.	2010	Effects of computer-assisted instruction on performance of senior high school biology students in Ghana	Ghana	Empirical study
Piper et al.	2018	Scaling up successfully: Lessons from Kenya's Tusome national literacy program	Kenya	Empirical study
Power et al.	2014	Educational Technology Topic Guide. HEART Topic Guides	Developing countries	Review
Tondeur et al.	2017	Understanding the relationship between teachers' pedagogical beliefs and technology use in education: a systematic review of qualitative evidence	Developed countries	Review
Trucano	2010	Worst practice in ICT use in education	N/A	Blog

Trucano	2016	ICT Framework Paper for Policy Analysis: Documenting national educational technology policies around the world and their evolution over time	N/A	Framework
UNESCO	2015	Information and Communication Technology (ICT) in Education in sub-Saharan Africa: A comparative analysis of basic e-readiness in schools	Sub-Saharan Africa	Review
Yunusa	2014	Effect of Computer-Assisted Instruction on Performance of Secondary School Students in Basic Technology Examination In Sokoto State, Nigeria	N/A - Theory or general discussion	Empirical study

In line with the realist research philosophy, and noting the limited existing literature base, we adopted an inclusive approach to reviewing this literature to enable us to generate as many insights about CAI use in LMICs as possible. All resources were read in full. In this process, two systematic reviews by Power et al. (2014) and Escueta et al. (2017) were particularly helpful in the conceptual sharpening process. Power et al's (2014) review explored whether EdTech is impacting learning outcomes in LMICs. The review assessed 83 studies including CAI interventions. Focused on developed countries, Escueta et al.'s (2017) review examined more than 100 studies of EdTech interventions including CAI. Although our research focuses on LMICs, Escueta et al.'s (2017) review brought a global perspective to current trends and successes.

These systematic reviews provided three important insights: 1) they confirmed that CAI has the potential to positively impact learning; 2) they highlighted that CAI can also negatively impact learning, and sometimes has no effect; and 3) they confirmed that there is a need for further research to understand why and how CAI impact varies so dramatically. For example, within Power et al's (2014) review, a study of a maths-focused CAI by Banerjee, Cole, Duflo, & Linden (2007) found up to a .47 standard deviation (SD) increase in scores, while Linden's (2008) report on a CAI intervention in India found that pupils in the experiment performed .57 SDs worse than the control. Of 29 CAI studies reviewed by Escueta et al. (2017), 21 revealed positive effects of up to .63 SDs, seven reported no change, and one, by Pane, McCaffrey, Slaughter, Steele, & Ikemoto (2010), reported a negative 0.19 SD impact.

Phase 1 - Re-read resources from experts

In Phase 1 we re-read and analysed each resource shared by the experts. All of these resources were used in developing the model presented in the results and discussions section. By including a range of varied resources, we generated insights into both the impact of CAI and the factors effecting the outcomes these interventions generate. The reviews and empirical studies provided an overview of the actual effects found in various countries. In a small number of cases these studies were also helpful in identifying some potential factors linked to positive outcomes, though often insights provide by these resources were minimal. The blogs, frameworks and conceptual pieces generally provided more detailed insights into the intended effects of CAI and the potential factors which could contribute to positive outcomes. While some resources were more useful than others (for example, Trucano (2016) informed six factors whereas Brusilovsky & Peylo (2003) informed one factor), all resources contribute to the model.

Phase 2 - Analysed studies in the Escueta et al. (2017) and Power et al. (2014) reviews

While the first phase of our research helped us to identify a number of factors contributing to the effects of CAI interventions, we also analysed the three CAI-focused studies from Power et al's (2014) review to validate these factors and identify other factors not described in any of the sources

in Phase 1. All three of these studies were randomised control trials. Table 4 provides a summary of the studies.

Table 4: *Studies reviewed in Phase 2*

Author(s)	Year	Title	Location	Impact
	Power et al. (2014)			
Banerjee et al.	2007	Remedying Education: Evidence From Two Randomized Experiments In India	India	+ .35 SDs
Lai, Zhang, Shi, Boswell, & Rozelle	2012	Does Computer-Assisted Learning Improve Learning Outcomes? Evidence from a Randomized Experiment in Public Schools in Rural Minority Areas in Qinghai, China	China	+ .19 SDs
Linden	2008	Complement or Substitute? The Effect of Technology on Student Achievement in India	India	- .57 SDs

The findings from the reviews of these studies endorsed the approach taken in Phase 1 where we include grey literature and resources that did not focus explicitly on CAI. While the RCTs showed the effects of CAI interventions on learning outcomes they provided few insights into the factors that influenced these results. While insights from Lai, Zhang, Shi, Boswell, & Rozelle (2012) have been included in our model, the studies by Banerjee et al. (2007) and (Linden, 2008) did not provide insights that were incorporated into the model.

RESULTS

Through our research we identified various factors that are likely to influence the outcomes of CAI interventions that policymakers and program designers should be cognizant of when designing CAI interventions in LMICs. These factors, which can either facilitate or impede increases in learning outcomes are:

- The operating environment;
- Stakeholder engagement;
- Infrastructure;
- Technological trust;
- CAI tool design;
- Content curation/creation;
- Student engagement;
- Integration;
- Teacher capacity;
- Student capacity; and
- Data collection and use.

The data in Table 5 below maps the factors to the resources which supported their inclusion in the model.

Table 5: *Factors influencing CAI intervention outcomes mapped to supporting resource*

Factor	Supporting resources
The operating environment	Carlson (2013); Chris, (2015); Trucano (2016).
Stakeholder engagement	Rose (2002); Hsu et al. (2013); Trucano (2016); UNICEF (2018).
Infrastructure	Carlson (2013); UNESCO (2015); Trucano (2016); UNICEF (2018).
Technological trust	Masingila et al. (2018); UNICEF (2018).
CAI tool design	Soe, Koki, & Chang (2000); Brusilovsky & Peylo (2003); Owusu et al. (2010); Power et al. (2014); Yunusa (2014); McEwan (2015); Escueta et al. (2017); Istance & Paniagua (2019).
Content curation/creation	Owusu et al. (2010); Yunusa, (2014); Power et al. (2014); Evans & Popova (2015);
Student engagement	Lai et al. (2012); Carlson (2013); UNICEF (2018); Muralidharan et al. (2019).
Integration	UNESCO (2015); Istance & Paniagua (2019); Muralidharan et al. (2019)
Teacher capacity	Tondeur, van Braak, Ertmer, & Ottenbreit-Leftwich (2017); Trucano (2010, 2016; UNICEF (2018)
Student capacity	Yunusa (2014).
Data collection and use	S. Carlson (2013); Power et al. (2014); Trucano (2016); Piper et al. (2018).

For an understanding of the model, the following are noteworthy. First, in line with realist theory development approaches, this is a mid-range model relating to a family of interventions, not one intervention applied in a single context. As a mid-range model, it applies to the general deployment of CAI interventions in LMICs. Second, we did not find enough evidence to establish causal linkages between the factors and changes in learning outcomes. In fact, none of the resources reviewed attempted to establish causal connections between these factors and the results of interventions. This reiterates the need for further research. As such, the model is not a causal model. Rather, it aims to highlight factors that influence whether CAI can contribute to improved learning outcomes.

Below we provide a brief description of each of these factors, the relationship between them, and how they impact the deployment of CAIs. This description is followed by a diagrammatic representation of the model in Figure 1.

Operating environment: Understanding the operating environment and ensuring that the CAI tool and intervention are designed to align with it, underpins successful CAI interventions. As outlined by Carlson (2013) and Trucano (2016), understanding the operating environment requires exploring many varied social, cultural, economic and religious considerations. It also requires generating detailed insights into the education system. This might include gaining familiarity with the policy environment, pedagogical approaches, curriculum design and trends in school infrastructure amongst others (Chris, 2015). A robust understanding of the operating environment will help to ensure that the CAI intervention aligns with the local context, which will in turn facilitate uptake and minimise resistance amongst users and the broader education community. In contrast, an inadequate understanding of the country/local operating environment can lead to the critical failure of CAI interventions. This foundational stage underpins all other elements of the model.

Stakeholder engagement: While none of the CAI-focused articles describe stakeholder engagement processes, Hsu et al. (2013), Trucano (2016), and UNICEF (2018) all emphasize the

importance of engaging with local communities in planning and implementing EdTech interventions. This process is particularly important in LMICs, where EdTech tools designed for European or American contexts are often transplanted without consideration of local capacity and needs. The previous step - developing an understanding of the operating environment - will help ensure that program designers know which stakeholders are most important to engage with and which engagement approaches will be most effective in the local context. Engaging with stakeholders provides various benefits that are built on throughout the development and deployment of CAI interventions. Engagement can help to provide greater insights into the local operating environment, which in turn can inform the design of both the CAI tool and the roll out of the tool (such as training and communication.) Stakeholder engagement has also been found to provide opportunities to foster champions who can advocate for CAI, and generate feelings of trust that may positively impact uptake (Rose, 2002).

Infrastructure: Intervention designers must ensure that appropriate infrastructure is in place to deliver the program. Carlson, (2013), Trucano (2016) and UNICEF (2018) all note that in LMIC contexts foundational infrastructure, such as electricity and Internet, cannot be presumed to be in place. For example, electricity supply is limited in many LMICs in Africa, a challenge which must be considered during CAI intervention design (UNESCO, 2015). Given this, adequate consideration must be given to the hardware that is used, with Carlson (2013) in particular advocating for the use of tablets rather than mobile phones or desktop computers. Regardless of the device selected, consideration must also be given to supplementary issues such as how the devices will be secured and the way that ongoing support – both technical and pedagogical – will be provided, particularly to those in remote communities. All consideration about infrastructure must be informed by an understanding of the local operating environment combined with additional insights provided by stakeholders throughout the engagement process.

Technological trust: Masingila et al. (2018) found that when teachers believe in the potential for technology to improve learning outcomes they are more likely to integrate it into the classroom. Similarly, UNICEF, (2018) highlighted the important role that local leaders play in fostering a culture where technology and innovation are welcome. Stakeholder engagement processes are a key part of helping to build trust amongst local stakeholders such as teachers, parents and students. When considering the development of technological trust CAI intervention designers are aiming to ensure that users and stakeholders possess appropriate technological trust to be willing to try the program. Additionally, the higher the levels of technological trust the more likely it is that users will possess some resilience to overcome any challenges that emerge during uptake and mainstreaming.

CAI tool design: A robust, engaging and interactive CAI tool design is important to ensure both students and teachers have a positive experience leading to ongoing use (Owusu et al., 2010; Soe et al., 2000). Escueta et al. (2017), McEwan (2015), Owusu et al. (2010), Power et al. (2014), and Yunusa (2014) highlight factors which should be considered during the design of the CAI tool which can lead to enhanced student and teacher uptake. The tool should include an engaging interface, leverage various mediums, support independent and self-paced learning, provide immediate feedback, and minimise technical glitches. Additionally, Brusilovsky & Peylo (2003) argued that high-quality CAI tools should include adaptive navigation, adaptive information filtering, intelligent collaborative learning facilities and adaptive peer group formation. Istance & Paniagua (2019) re-emphasize this view, noting that a good tool will allow students to control their learning experience. Carlson (2019) notes that the tool must also be well designed for teacher use. This means that any CAI tools should be easy to use, contain functionality to help teachers be more efficient/effective, support teachers to help students understand curriculum content, and be easy to integrate into current practices. The insights provide a starting point for CAI tool design. However, it is important that the final design is informed by feedback gathered through stakeholder consultation and testing, that the tool is aligned with the local infrastructure availability, and that it does not clash with any local cultural or social norms.

Content curation/creation: Interestingly, few of the empirical authors provided in-depth description of the content that was provided to students through the CAI tools they were deploying. Whilst some mentioned subjects and grade (for example Owusu et al. (2010) focused on high school biology and Yunusa, (2014) focused on a secondary level technology subject), none of the empirical researchers provided a high level of detail about the type of content that was deployed through the CAI tool. This was an area where the grey literature and broader EdTech materials were particularly useful in supporting the development of our model. For example, in their review exploring what is required to facilitate learning in developing countries, Evans & Popova (2015, p. 13) highlight that "computer-assisted learning programs are ineffective when instruction is not tailored to each student's level of knowledge" or "when technology distribution is unaccompanied by parent or student training". Our research found that for CAI to impact learning it must contain appropriate, quality, educational content. This means CAI tool content should be connected with the national curriculum, contain a range of resources including videos, games and assessments, and be aligned to student ability level (Evans & Popova, 2016; Owusu et al., 2010; Power et al., 2014).

Student engagement: Ensuring students want to use the CAI tool is an important step in using CAI to enhance learning outcomes. Carlson (2013), Muralidharan et al., (2019) and UNICEF (2018) all highlight the link between delivering appropriate content to students and higher levels of engagement. Lai et al. (2012) found that as well as increasing learning outcomes, the use of CAI was key to increasing student interest in both the subject supported through the CAI intervention as well as other subjects. Using CAI can help teachers ensure students at different levels receive appropriate content, particularly in LMIC contexts where a single classroom may include a wide range of age groups and capacity levels. Ensuring appropriate content is being accessed by students can help to build student engagement which will in turn help to increase learning outcomes.

Integration: It is important to emphasize that CAI tools are a complement to teaching. They should not aim to replace teachers. Ensuring CAI tools are appropriately integrated into the teaching-learning process is key to generating improved learning outcomes. Istance & Paniagua (2019) suggest that the local context (such as number of teachers, capacity of teachers, etc.) can influence how CAI tools can be integrated most successfully. This again indicates the importance of developing a robust understanding of the operating environment and engaging with local stakeholders to understand local needs. Facilitating integration is a key part of a high-quality CAI intervention design. Integration might involve supporting differentiated learning in a crowded classroom or delivering content when teachers have not received adequate training. If the CAI intervention is poorly planned – for example if it reduces the time for other high-quality activities but does not bring significant benefits – then it can negatively impact learning. This element of integration really highlights the focus that must be placed on the broader CAI intervention, rather than just the tool itself. Integration can be achieved through training (see teacher capacity below), but also through other mechanisms such as embedding the use of CAI into policy and other formal commitments (UNESCO, 2015).

Teacher capacity: Ensuring teachers are trained to effectively use CAI is central to any CAI intervention. Once intervention designers have identified how the CAI tool will be integrated into the teaching/learning process, teachers must be trained to ensure they have the capacity to deploy the tool in line with the intentions of intervention designers (Trucano, 2010). UNICEF (2018) emphasises the need to identify and foster the skills teachers need to use any type of EdTech and, where possible, build them into the broader frameworks of teacher development. In a CAI intervention this would mean that teachers are both encouraged to use the CAI tools but also held accountable for appropriately integrating them into their teaching practices. Training should cover the practicalities of using the tool such as device operation, how to teach students to use CAI, how to access ongoing technical support, and, most importantly, how to integrate the tool into classroom

activities (Trucano, 2016). Training for teachers can also create an important foundation for positive engagement with CAI, including a resilience to overcome any technical challenges that might emerge, particularly during early deployment. As teachers may initially have beliefs that are a barrier to incorporating technology into the classroom any training should be designed to ensure that it addresses any concerns by highlighting the use of the technology both to support better learning outcomes and to simplify existing teacher practices and processes (Tondeur et al., 2017).

Student capacity: While ensuring teachers are adequately trained for their role in CAI interventions is important, understanding whether students have the capacity to use the tools is also essential. Yunusa (2014) identified that most users in the empirical trial did not have the skills/competencies to engage with the content delivered to them, hindering the ability for the tool to improve learning outcomes. Developing an understanding of the capacity of students is again linked to understanding the operating environment and consulting with local stakeholders. Once an understanding of student capacity is obtained, the CAI tool (and the content within it) must be designed to align with the student capacity. Student capacity to use the tool is also important to consider. Teachers should be equipped to train students in how to use the CAI tool. Similar to the capacity of teachers, a high-quality training experience can create resilience to continue with use despite technical challenges.

Data collection and use: A powerful benefit of CAI tools is their ability to collect, analyse and report on data in various ways. This can include collecting data from students to support differentiated teaching, collecting CAI usage data to inform oversight by central level actors, generating insights to inform teacher training, or using CAI to assess students (Trucano, 2016). Data collection can also inform implementation quality/fidelity assessments (for example, is hardware in place, are teachers using devices), which can, in turn, support iterative adjustments as implementation lessons are learned (S. Carlson, 2013; Piper, Destefano, Kinyanjui, & Ong'ele, 2018; Power et al., 2014).

Improved learning outcomes: Each of the six CAI-focused studies identified through the Escueta et al. (2017) and Power et al. (2014) reviews measured changes in learning outcomes. However, the studies re-emphasized the fact that CAI use generates varied outcomes (four studies found positive outcomes as high as .63 SDs, while two studies found negative outcomes as low as .57 SDs). As such, this model does not posit causal links between the above elements and better learning outcomes due to the complexity in identifying changes in learning – the final goal of improved learning outcomes is deliberately not linked as an outcome in Figure 1 below. Rather, the model retains the reference to learning outcomes to ensure that the focus on generating improvements in learning remains central in the design of any CAI intervention.

This model highlights that successful CAI deployment must look beyond developing technology and consider the varying needs of different actors across multiple phases of intervention development and deployment. The model highlights the need to engage stakeholders early, ensure that CAI interventions are developed in line with the local context and curriculum, develop the capacity of teachers to integrate the tool into the teaching-learning process, and ensure the ongoing availability of both technical and pedagogical support.

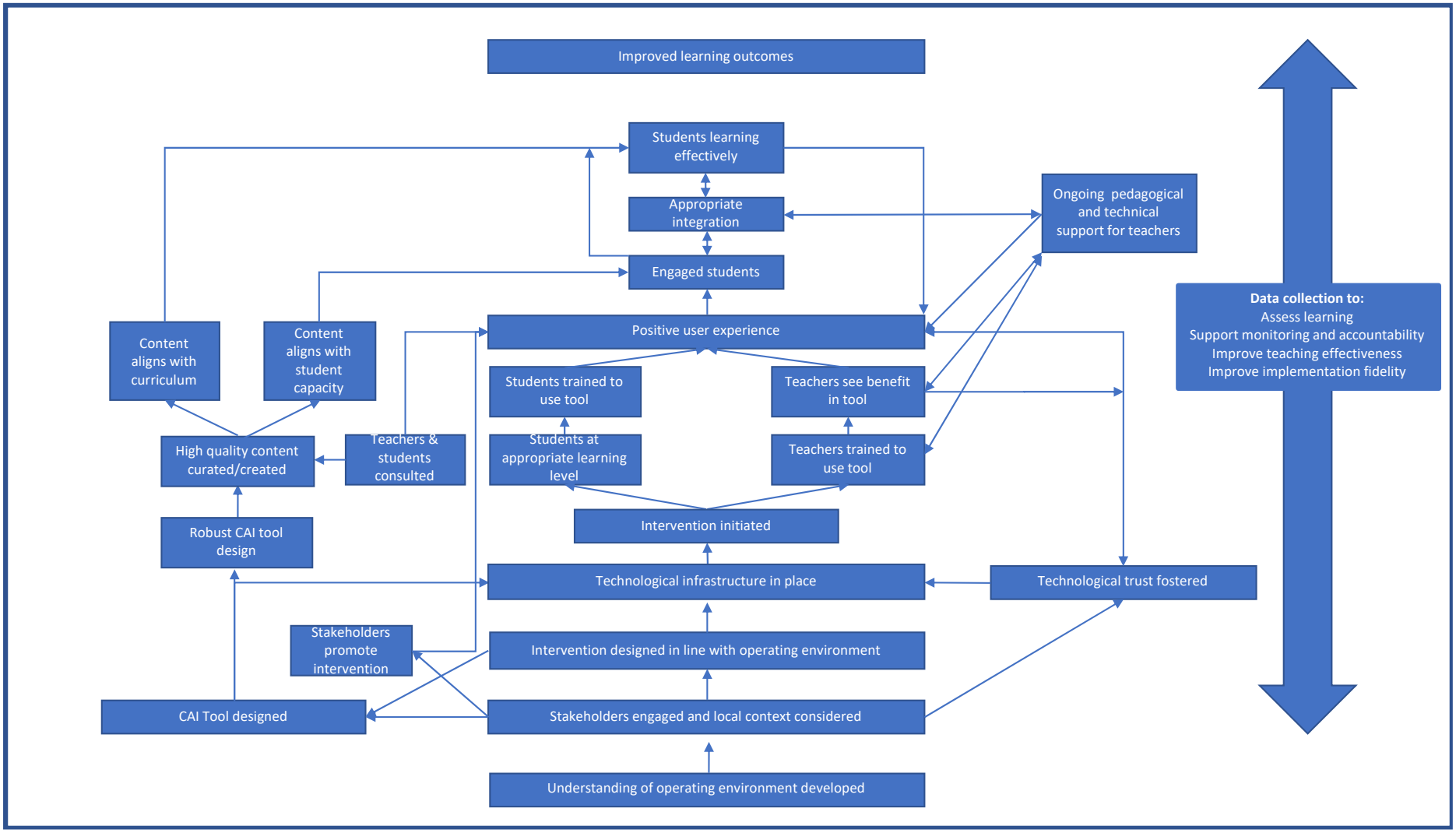

Figure 1: Diagrammatic representation of factors affecting CAI intervention outcomes

DISCUSSION AND CONCLUSION

The low learning outcomes in LMICs require rapid and innovative changes to education service delivery to disrupt the status quo. Integrating EdTech with traditional approaches may be an effective way to drive change. This research set out to investigate the role CAIs could play within this process, and, in particular, identify the factors that either positively or negatively influence changes in learning outcomes driven through CAI interventions. After consulting with 13 experts in the education field, and reviewing 21 resources recommended by these experts, the research presented a model to explain the factors that impact the learning outcome changes driven by CAI. The authors now recommend further research be undertaken that focuses on exploring these factors in more detail, and further strengthening the theory presented.

While the model helps us understand the factors to consider when deploying CAI in LMICs, further research is required to refine the model. The weakness of CAI research to date means that the model had to draw heavily on grey literature sources. While the model does include a number of insights generated from empirical studies, most of these studies do not robustly explore the myriad of issues that lead to the diverse sets of results. This lack of evidence is compounded in LMIC contexts, where political, cultural, and financial complexities complicate education service delivery, and are often not referenced in empirical work. Various initiatives can be pursued to further refine the model.

First, a more comprehensive systematic review focusing solely on the use of CAI in LMICs is required. This review should not focus on whether CAI can improve learning outcomes, but rather aim to uncover more detail on interventions that led to a set of results. These insights can then be used to generate a refined model.

Second, any further work in this space should be directly linked to substantive technology theories. Few resources in this research – particularly amongst the grey literature - were influenced by formal/substantive theory. Those that did focused on educational theories (e.g. Yunusa's (2014) work was based on Masie's blended learning theory). There was little reference to theories such as diffusion of innovation theory (Rogers, 1983) or the unified theory of acceptance and use of technology (Venkatesh, Thong, & Xu, 2016) which have informed the introduction of technology in other sectors such as healthcare. Either of these theories would be useful lenses to probe and then refine the model.

Third, the research should pay close attention to various issues that are touched upon but are not explored in enough detail in the resources to be included in the model. Some examples of this include issues such as national ICT policy development, cost-effectiveness, opportunity costs, and program oversight and accountability.

Finally, it is important to note that none of the CAI interventions analysed during the development of the model were deployed at scale. Most focused on one or two grades within a small handful of schools. Any further research should be structured in a way that explicitly acknowledges the importance and unique concerns that come when implementing EdTech interventions at scale.

LIMITATIONS

This research was developed based on resources generated through consultations with experts in the education field. While the benefits of this approach mean that we have captured a range of up-to-date resources that may not have been located through a traditional literature review, it means that the resources included do not comprehensively capture all the available research on this topic.

As the resources came recommended by experts there was no explicit assessment of quality undertaken to filter the resources provided.

Additionally, the resources used to inform the review were limited to those written in English, potentially excluding resources generated that were written in the native language of authors from LMICs.

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