British Journal of Educational Technology *Vol 51 No 2 2020* 498–514
doi:10.1111/bjet.12870

The potential and prerequisites of effective tablet integration in rural Kenya

Carolyn J. Heinrich, Jennifer Darling-Aduana and Caroline Martin

Carolyn J. Heinrich, Ph.D., is the Patricia and Rodes Hart Professor of Public Policy, Education and Economics in the Peabody College at the Vanderbilt University. Her research focuses on education, workforce development, social welfare policy, program evaluation and public management in the United States and other international contexts. Jennifer Darling-Aduana, M.Ed., is a doctoral student in the Department of Leadership, Policy and Organization, Peabody College, Vanderbilt University. Her research focuses on mechanisms to reduce educational inequities in the United States, with particular attention to student–teacher–curriculum interactions and how digital learning transforms teaching and learning processes in schools. Caroline Martin, M.Ed., is a Research Analyst at the Tennessee Department of Education. She has taught and led professional development and conducted educational research in a variety of settings, including large urban school districts in the United States and in international settings such as Nicaragua and Kenya. Address for correspondence: Carolyn J. Heinrich, Patricia and Rodes Hart Professor of Public Policy and Education, Department of Leadership, Policy, and Organizations, Peabody College, 230 Appleton Place, Nashville, TN, USA. Email: carolyn.j.heinrich@vanderbilt.edu

Abstract

This study investigates how pedagogical, cultural and institutional factors interact with technical knowledge in educational technology integration and how they relate to equitable and effective technology use in low-resource settings. In the context of a one-to-one tablet initiative in rural Kenya, we explore how these factors constrain or support access to technology, instructor capacity, student engagement and student learning, as well as their implications for reducing educational and digital divides. We employ a mixed methods, such as a quasi-experimental (prepost, nonequivalent control group) research design that draws on data from classroom observations, teacher interviews, student surveys and focus groups, and assessments of student academic performance to generate evidence on classroom practices and student learning in schools with access to tablets, while also highlighting core challenges to successful technology integration. Our findings contribute to the identification of prerequisites and supporting factors for successful educational technology integration, as well as policy levers and school-based strategies that are likely to increase equitable access to quality learning experiences in schools in low-resource contexts.

Introduction

In the face of an increasingly competitive, global knowledge economy, governments, schools and nongovernmental organizations are turning to information and communication technology (ICT) as a means to increase student engagement and learning. Policymakers also see ICT as a promising strategy for improving access to educational resources and enhancing teachers' ability to meet diverse student needs, particularly in low-resource settings where schools may lack sufficient funds to meet basic operating and educational costs that support access to the physical infrastructure, technical capacity and human capital (Herodotou, 2018; Twining, Raffaghelli,

Practitioner Notes

What is already known about this topic

- A lack of funding, planning and infrastructure hinder information and communication technology (ICT) integration.
- Procurement of educational technology and infrastructure improvement efforts has reduced digital divides, but learning divides persist in implementation.
- Insufficient teacher technology expertise and professional development constrain teacher's effective use of educational technology in classrooms.

What this paper adds

- We employ mixed methods—triangulating the student assessment data with data from student surveys and focus groups, teacher interviews and classroom observations—to identify how pedagogical, cultural and institutional factors interact with technical knowledge in ICT integration in ways that support or constrain student learning in low-resource contexts.
- We find that more attention is needed for cultural factors that interact with pedagogical and technical skills to ensure that the classroom instructors' attention is equitability distributed in ways that discourage in-class "tracking" and differential access to quality learning experiences, such as some teachers' disregard of "slow learners" in the classroom.
- In low-resource contexts, providing even basic levels of infrastructure (eg, a consistent power source) and access to general technical knowledge requires more creative and concerted efforts from school leadership and instructors, such as the offer of tutorials and reading clubs outside of the class to expand access and improve the use of devices.

Implications for practice and/or policy

- We find that device sharing can have positive effects on peer-to-peer learning, which suggests that policymakers in Kenya should weigh the benefits of achieving *one-to-one* device access against the potential advantages of alternative investments, such as expanding professional development on the integration and use of currently available devices.
- Increasing opportunities for peer-to-peer learning and exchange (among teachers and students) and building shared capacities for ICT integration can help reduce technical issues and lost instructional time.

Albion, & Knezek, 2013; Warschauer, Knobel, & Stone, 2004; Wong, Li, Choi, & Lee, 2008). Among these are policymakers in the Ministry of Education in Kenya, which rolled out the ICT Integration in Primary Education (or Digital Literacy) project as one of its flagship programs for improving teaching and learning in Kenya's public primary schools. The project components include improvements in the ICT infrastructure and procurement of devices, development of digital content and capacity building of the teachers, which were built on rural electrification efforts initiated with the 2006 Energy Act.

Despite the promise and hype, the literature is rife with discussions of the challenges of integrating technology and ensuring equitable access across a broad range of educational contexts

(Hohlfeld Ritzhaupt, Barron, & Kemker, 2008; Warschauer & Matuchniak, 2010). In this research, we delved deeply into a setting in rural Kenya, where public schools and a community-based nonprofit partner are collaborating in implementing a one-to-one tablet initiative in primary schools under the Digital Literacy Project. The goals of this eReader (tablet) initiative, supported by the Lwala Community Alliance (LCA), include improving access to educational resources, enhancing classroom learning and increasing student achievement for students in North Kamagambo, Kenya. Toward that end, the LCA designed and implemented a pilot program that provided eReaders equipped with course books and supplementary books to Class 6 teachers and students at three primary schools in this region. At approximately five percent, the cost of laptops and tablets (eReaders) may not only be a more viable option in low-resource contexts, but they are also potentially more suitable for younger (primary school) learners (Herodotou, 2018; Tamim, Borokhovski, Pickup, & Bernard, 2015).

Our study addressed the following key questions within this research context: (1) How, and to what extent, was tablet integration associated with any observed changes in students' educational opportunities in rural Kenya? (2) What are the primary challenges to successful technology integration in resource-constrained contexts? (3) What policy levers and school-based strategies are likely to improve the equitable access to quality learning experiences and overcome persistent infrastructure challenges within this context?

ICT integration in low-resource, educational contexts: Theory and evidence

Theoretical framing

Two of the most widely used frameworks for conceptualizing investigations of ICT integration are the substitution, augmentation, modification and redefinition (SAMR) and technological pedagogical content knowledge (TPACK) models (Mishra & Koehler, 2006; Puentedura, 2013). The SAMR (see Figure 1) provides a scaffold for characterizing learning tasks in terms of the depth and complexity of technology integration, broadly classifying the technology use as either enhancement or transformation. We situate the use of technology in North Kamagambo schools

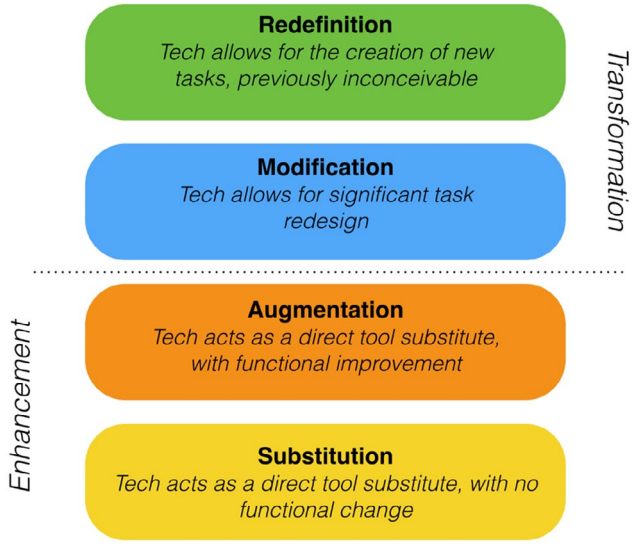

Figure 1: Substitution, augmentation, modification and redefinition (SAMR) model. Source: Puentedura (2013) [Colour figure can be viewed at wileyonlinelibrary.com]

primarily in the enhancement domain, in part because of the limitations of the technology (eReaders) and the ICT infrastructure (eg, lack of Internet access). In the most basic form (substitution), teachers use the technology as a substitute for previous instructional approaches, with no changes in instructional processes. To the extent that technology use improves on teaching or learning process (that could be undertaken with or without technology), the SAMR categorizes this technology use as augmentation (Puentedura, 2013). Alternatively, for technology use to facilitate transformative teaching—that substantially alters learning tasks in ways not possible without the technology—teachers are expected to use the technology for the significant redesign or reimagining of instructional approaches and learning opportunities (Puentedura, 2013).

Teacher approaches to technology integration in the classroom are influenced not only by their knowledge of the technology and how to enact features embedded in it for enhancing or transforming learning (Orlikowski, 2000; Orlikowski and Gash, 1994; Rogoff, 2003), but also by their pedagogical and content knowledge, as shown in the TPACK model in Figure 2 (Mishra & Koehler, 2006). This framework identifies intersections of two or three of these domains (technological, pedagogical and content knowledge). The TPACK illuminates our understanding of how teachers conceive of and enact the technology in ways that are consistent with their pedagogical beliefs and practices and/or their content expertise (Hilton, 2016). Because the eReaders in North Kamagambo, Kenya were used to support access to books for language learning and reading comprehension, we focus primarily on the TPK (technological and pedagogical knowledge) intersection in the TPACK model. We also draw the sociocultural theory into our discussion of these domains. The sociocultural theory that submits cultural norms and conventions transacted by students and teachers in the classroom will influence how teachers and students understand the

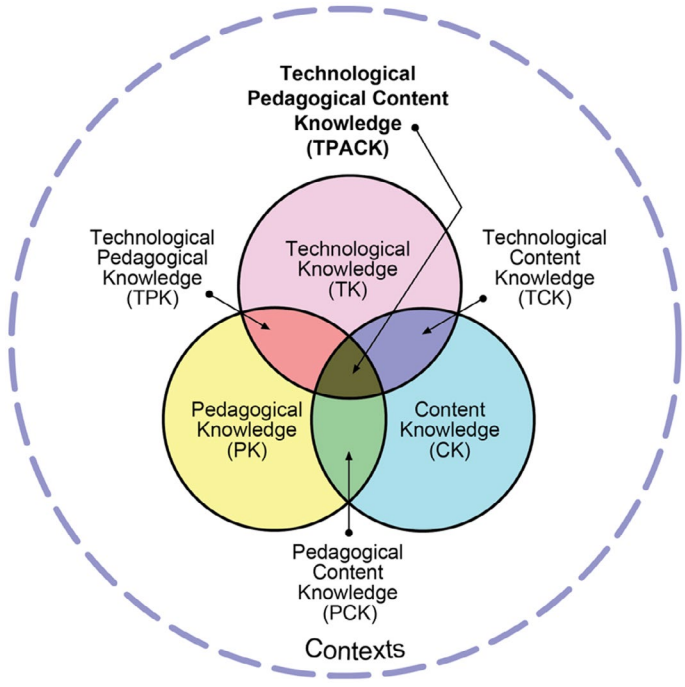

Figure 2: Technological pedagogical content knowledge (TPACK). Source: Mishra and Koehler (2006) [Colour figure can be viewed at wileyonlinelibrary.com]

properties of the tablets, as well as how they rely on other individuals and classroom resources to support their learning (Nasir & Hand, 2006).

For example, the TPK intersection motivates us to examine how teachers deploy their technological and pedagogical knowledge in grappling with the limitation of an insufficient number of tablets to facilitate one-to-one device access in their classrooms. The sociocultural theory, moreover, leads us to ask how in the face of higher than desired student-to-tablet ratios, cultural norms may affect student access to or interactions around shared devices. Used in combination, these theoretical frameworks help us to identify, classify and interpret the pedagogical, cultural, institutional and technical factors observed in this study of ICT integration.

Evidence on ICT integration in low-resource settings

Existing research confirms that a range of pedagogical, cultural, institutional and technical factors have the potential to contribute to (or reduce) ongoing inequities in the use of educational technology to support student learning (Hohlfeld *et al.*, 2008; Warschauer & Matuchniak, 2010). For example, studies of ICT integration in low-resource settings have found more turnover and variability in teaching and administrative staff, which hinders the planning for and implementation of educational technology in classrooms (Warschauer *et al.*, 2004). This personnel challenge also likely reduces the pool of technical knowledge available to educators in a given school, particularly in countries where the professional development on ICT integration is limited. And it may further dilute the effectiveness of technology-based initiatives in subsequent years and preclude teachers from moving beyond substitution (in the SAMR) to reimagining what is possible with technology use. Research shows that even when teachers have confidence in or experience with the technology being introduced, they are frequently challenged in low-resource contexts by disadvantages such as larger class sizes, more students with limited technology experience, and inadequate pedagogical and other instructional supports (Darling-Aduana & Heinrich, 2018; Warschauer *et al.*, 2004).

Some of the most common barriers to ICT integration identified in prior research in developing country contexts include: insufficient teacher technology expertise, ineffective educational software, access issues and lack of alignment with educational norms or expectations (Buabeng-Andoh, 2012; Pelgrum, 2001; Venezky, 2004). Mndzebele (2013) identified the lack of funding, planning and professional development as major obstacles to ICT implementation in Swaziland. Likewise, in Ghana, 85 percent of preservice teachers reported that they lacked appropriate training to use ICT (Gyamfi, 2016). While the lack of Internet connectivity was observed as a limiting factor across continents, the lack of reliable electricity also restricted the technology use in studies set in Africa (Kenya, South Africa) and Asia (Cambodia) (Richardson, 2011; Stols *et al.*, 2015). Multiple studies have also shown that across contexts, access to technical support, professional development and other forms of assistance expand general technical knowledge that is foundational to the enhancement and transformation (in SAMR) and to the interaction of technological and pedagogical knowledge (TPK) in ways that support technology use (Buabeng-Andoh, 2012; Pelgrum, 2001; Richardson, 2011; Stanhope & Corn, 2014; Venezky, 2004).

Through our theory-informed investigation and in-depth depiction of the educational technology integration in a rural, Kenyan community, we build on the contributions of prior research to identify some of the prerequisites for improving student outcomes through ICT integration in low-resource contexts. We also draw out new insights for educators and policymakers. Our mixed methods study goes beyond the technical challenges of ICT integration to also examine the pedagogical, cultural and institutional factors that support or constrain the effectiveness of ICT integration in increasing student learning and engagement, formed through the analysis and

triangulation of the assessment data, student surveys and focus groups, teacher interviews and classroom observations. We begin by describing our research setting, samples, and intervention, study data and measures and methods below.

Study samples, data and methods

Setting, samples and intervention

The eReader initiative began in North Kamagambo, Kenya in 2016, through a collaboration between the LCA and rural, government-funded primary schools in this region of Western Kenya. The eReaders were provided by Worldreader, an international provider of tablets to developing countries, and distributed by the LCA for teacher and student use in three primary schools in the region. With the objective of understanding how the introduction of the eReaders would affect student learning, the LCA and the partnering researchers implemented a mixed methods study. A quasi-experimental, nonequivalent control group design was used in selected schools to participate. The LCA Education Team first categorized all 13 schools in the region by their average scores on the 2014 Kenya Certificate for Primary Education (KCPE) test into three distinct achievement tiers (low, middle and high). A total of 10 primary schools in North Kamagambo subsequently submitted proposals to participate in the eReader initiative. The LCA Education Team then selected two proposals from each of the three preestablished achievement tiers, while also factoring in both the treatment and control schools' commitment to work with LCA and the intent to involve one school from each subarea.

Because the selection of classrooms for eReader distribution was made via the criteria discussed above (and not via random assignment), we adjust for pretreatment differences in estimating *associations* between the eReader program and student's outcomes and do *not* interpret any estimates as causal. Table 1 presents summary statistics and tests of statistical significance for differences between the characteristics of the treatment and comparison groups at the baseline, including pretreatment academic assessments. The additional baseline survey questions designed by the LCA were intended to gauge students' access to books at school in the absence of eReaders, as well as at home, and to measure student motivation to read and caregiver support for reading and learning at home. These descriptive statistics show that students in classrooms receiving the eReaders scored significantly lower on three measures of academic performance at the baseline (before the 2016 school year): oral reading fluency in Kiswahili and English, and Kiswahili comprehension. For the other five measures of pronunciation and comprehension, there were no statistically significant, pretreatment differences in academic performance between the treatment and comparison group members. In addition, children in classrooms with eReaders reported having more access to books at school and at home at the baseline, but they were also older and significantly more likely to report that they "only read when they had to."

Within treatment schools, LCA distributed 150 eReaders to Class 6 classrooms in February 2016 in proportion to the number of teachers and students at each school, with the intent for each school to have a sufficient number of eReaders to realize a one-to-one ratio between students and the tablets. All eReaders were loaded with Class 6 workbooks and supplementary reading in Kiswahili and English. Teachers integrated the tablets in math, reading, social studies, science, Kiswahili and religion classes. Kiswahili, one of the official languages of Kenya, was the primary focus of instruction in 22 percent of observations.

Table 1: Baseline characteristics of eReader treatment and comparison groups, 2016 school year

	Treatment group			Comparison group				
	N (students)	*Mean*	*Std. Dev.*	*N (students)*	*Mean*	*Std. Dev.*	*Mean difference (T-C)*	*p-value*
Baseline academic performance								
% correct words: Kiswahili	95	0.88	0.22	128	0.89	0.19	−0.009	.736
% correct words: English	95	0.51	0.25	128	0.51	0.21	0.006	.841
Kiswahili correct words per minute	95	44.67	23.10	128	63.23	31.68	**−18.565**	.000
English correct words per minute[1]	84	68.74	22.19	119	95.98	33.92	**−27.246**	.000
Kiswahili comprehension	95	2.40	1.88	128	3.18	2.04	**−0.780**	.004
English comprehension	95	3.42	2.09	128	3.64	2.05	−0.220	.434
Kiswahili comprehension (incorrect)	95	3.79	2.16	128	3.38	2.06	0.407	.155
English comprehension (incorrect)	95	2.77	1.95	128	2.87	1.96	−0.099	.710
Student characteristics (pretreatment)								
Parents are primary caregiver	94	0.71	0.45	127	0.64	0.48	0.08	.243
Male	94	0.50	0.50	127	0.54	0.50	−0.04	.526
Age	93	12.88	0.15	127	12.39	0.10	**0.49**	.005
Access to less than five books at school	94	0.12	0.32	127	0.16	0.37	−0.04	.349
Access to 5–10 books at school	94	0.46	0.50	127	0.69	0.46	**−0.23**	.000
Access to more than 10 books at school	94	0.43	0.50	127	0.15	0.36	**0.28**	.000
Less than five books at home	93	0.37	0.48	128	0.69	0.47	**−0.32**	.000
Child: I read only when I have to	95	0.51	0.50	128	0.29	0.46	**0.22**	.000
Caregiver rarely/never reads to child	95	0.25	0.44	128	0.18	0.39	0.07	.188
Caregiver rarely/never checks schoolwork	95	0.21	0.41	128	0.20	0.40	0.01	.893

Notes Statistically significant mean differences are shown in bold. The comparison group consists of students attending schools that volunteered for the eReader initiative but were not selected to implement it.

[1]Some students did not complete the English correct words per minute assessment, resulting in fewer observations for the analysis of this outcome. Analyses were conducted to assess the sensitivity of study findings to the loss of observations.

Data collection and measures

Analyses of assessment and survey data were supplemented with emergent findings from a grounded theory analysis of data collected from classroom observations, student focus groups and teacher interviews. Below, we describe our data collection processes and resulting data sources in detail.

Assessment data

The program administrative data included baseline (pre) test scores for assessing student achievement and end line (post) test scores that enable us to examine associations between student tablet use and changes in their academic performance relative to other primary schools. Because pilot testing suggested that the fluency and comprehension levels of Class 6 students would be too advanced for the Early Grade Reading Assessment (EGRA) and Progress in International Reading Literacy Study (PIRLS) assessments, a custom evaluation tool was developed by an LCA Monitoring and Evaluation (M&E) team member. This tool draws on the EGRA and PIRLS assessments, as well as the input from a U.S.-based elementary school psychologist who regularly uses standardized assessments to evaluate the reading abilities of primary school children. The assessment consists of evaluation of reading abilities containing three subtests on pronunciation, oral reading fluency and comprehension in both Kiswahili and English, sourced from Class 8 Kiswahili and English textbooks. The scoring of student performance on the assessments was calculated individually per subtest. Pronunciation of each word was scored on a 0-1 scale, where 1 point was awarded for the correct pronunciation and 0 points otherwise. During the reading passages, the students' total reading time and the number of incorrectly read words were tracked. Both metrics were used to calculate correct words per minute (CWPM). The comprehension section included multiple-choice questions, one-answer open-ended questions and multiple-answer open-ended questions.

Student surveys

A student survey was also administered to gather baseline information on student demographics, home environments, study habits, etc. (see again the measures in Table 1), as well as during the end line assessment, which included an additional set of questions to gauge students' educational aspirations. A total of 109 students from treatment schools and 144 students from comparison schools completed the baseline academic assessments and survey in January and February of 2016. These same assessments were completed by 112 students from treatment schools and 136 students from comparison schools at the end-of-the-school year (in November 2016). After linking the baseline and end line data to the survey data, a total of 223 observations with complete records were available for analysis—95 students in the treatment group and 128 students in the comparison group—although as indicated in Table 1, some students did not complete the English CWPM assessment. Our analysis of the sensitivity of our results to the loss of observations (without English CWPM) did change any research conclusions.

Classroom observations

We also conducted classroom observations of tablet use in the summer of 2016 in North Kamagambo, Kenya. Across all classroom observations, we used a well-tested, research-based instrument that enables observers to record the extent to which an instructional session (and integration of educational technology) facilitates quality learning opportunities for students (Burch, Good, & Heinrich, 2016), with some minimal adaptations to account for differences in classroom language use and infrastructure in rural Kenya. The observation instrument incorporates multiple dimensions that capture aspects of the physical environment; curricular content and structure; instructional model; interactions between teachers, students and the technology; student and teacher engagement; and any assessment of learning. The ratings of digital and

blended instruction are recorded on a 0-4 (5-point) scale; see additional information on each dimension in Appendix S.1 (online). Researchers also recorded the time lost to technology problems, the number of students per device, time allocated to various instructional strategies, and detailed narrative vignettes of instruction, activities and interactions in the classroom. A total of 36 classroom observations were conducted in the treatment and comparison schools.

Student focus groups

During the end line data collection, a random sample of students from both treatment and comparison schools participated in focus group discussions. Students were asked to provide their opinions on the use of eReaders in treatment schools and more generally on reading behaviors in treatment and comparison schools. (The full focus group protocol is available in Appendix S.2 online). A total of 17 students from treatment schools and 26 students from comparison schools participated in the focus groups.

Teacher interviews

The research team also conducted interviews with teachers to provide the context and insight into teachers' experiences. The interview data were collected using a semi-structured interview protocol with interview topics, probes and both closed- and open-ended questions. The interview topics included instructor background, instructional practices, support for the tablet use, tablet access and use by student subgroups, assessment of the effectiveness of tablets in the classroom and plans for their ongoing use. (Refer to online Appendix S.3 for the full protocol). In total, eight classroom teachers were interviewed.

Methods of analysis

We analyzed the data both quantitatively and qualitatively, using triangulation across sources of information, classrooms and settings to confirm the validity and reliability of analytical findings. In analyzing the qualitative data, interviews and focus groups were recorded, transcribed and subsequently analyzed in conjunction with observation and the survey data on tablet use in the classroom to identify emerging themes using a grounded theory approach. Spot-checking was used to check coding consistency. We also searched for exceptions and alternative explanations to challenge preconceptions and personal biases.

In regression analyses of the relationship of the tablet use to student academic outcomes, we estimated two alternative specifications: one that estimates the change in student achievement (1) from the beginning to the end of the 2016 school year (with the gain score as the dependent variable, $A_{it}-A_{it-1}$), and the other (2) that predicts the end line level of student achievement (A_{it}), controlling for the baseline student achievement (on the same measure) and other student characteristics at the baseline (X_{it-1}) as described in Table 1.

$$A_{it} - A_{it-1} = \alpha + \beta_1 \mathrm{eR}_{it} + \beta_2 X_{it-1} + \varepsilon_{it} \quad (1)$$

$$A_{it} = \alpha + \beta_1 eR_{it} + \beta_2 X_{it-1} + \beta_3 A_{it-1} + \varepsilon_{it} \quad (2)$$

We estimate robust, clustered standard errors that account for student clustering within classrooms. Given the 2016 rollout of the eReader program, we only have one baseline measure of achievement. Because we observe baseline differences between students in eReader and

comparison classrooms (suggesting the potential for unobserved differences in student characteristics as well), we do not make any causal assertions about the relationship between eReader use (eR_{it}) and changes in student outcomes. Nonetheless, research has established that the use of value-added models such as those that control for lagged measures of the dependent variables often substantially reduce bias in estimates (Chetty, Friedman, & Rockoff, 2014).

Findings

Our mixed methods analyses identified some improvements in educational opportunities for students in classrooms where the eReaders were integrated, including increased access to educational materials, enhanced student engagement and increases in measured academic performance. Our analysis also highlighted multiple barriers to effective eReader integration, such as inconsistent access to electricity, unintended device sharing and difficulties leveraging eReaders to transform instructional practices that could inform efforts to further improve the integration of eReaders in similar low-resource educational settings.

Improvements in educational opportunity and outcomes

While the number of tablets afforded by Worldreader grant was insufficient to maintain the intended one-to-one student-to-device ratio in all classrooms, seven of the eight interviewed teachers at tablet schools emphasized that the devices increased student access to textbooks. Prior to tablet adoption, as many as eight students shared a textbook. In other instances, only the teacher had access to course material, which he or she used to copy all exercises onto the whiteboard for students to copy into their exercise books. One teacher stated, "In a class environment with no books, the tablets help each pupil to work at their own pace because they each have their own tablet—they can use them anytime. They don't have to share with anybody." This represents an augmentation of learning tasks in the SAMR framework (Puentedura, 2013). Students in Kenya who participated in end-of-the-school year focus groups also gave positive feedback on the implementation of tablets in their classrooms and unanimously expressed a preference for tablets over standard textbooks. They highlighted aspects of the tablets such as their ability to efficiently find definitions of unknown words and to access interesting and varied books, and the fact that the tablets did not have missing pages like their textbooks. The students' perspective likewise illuminates how the tablets augmented learning opportunities, providing functional improvements over the textbooks they replaced.

We accordingly observed high levels of digital citizenship or the extent to which students used the eReaders as intended by the instructor. Comments from teachers suggested that the observed behavior reflected students' respect and appreciation for the opportunity to use tablets and classroom cultural norms regarding teacher authority. Teachers also noted in interviews that the tablets had improved student engagement. Teachers' evidence for this included decreased student absenteeism and drop-out rates, as well as an observed shift in students' attitudes toward learning. With respect to students' physical attendance, one teacher stated that since they received tablets, students were rarely absent. Another provided specific numbers, saying that, "In the past, we had two to three (drop-outs) per term, but this time, they have not (dropped out)." Yet another teacher mentioned that at least three students transferred to the tablet schools from other schools.

Teachers attributed these changes to a shift in students' mindset associated with the opportunity to use tablets. As one teacher explained, "Now pupils like school. Being in school leads to getting something out of that school." Teachers described students as working more without being told, even without the teacher present in the room, as well as students coming in as early as 6:30 in

the morning to read storybooks on the tablets. Furthermore, they suggested that tablets increased motivation among students in other classes, who attempted to compete with the students with tablet access. One teacher also mentioned that the tablets improved teacher–student relationships by increasing opportunities to communicate with one another, a change potentially leveraged by advances in technological and pedagogical knowledge (TPK) through tablet integration. This was evident in classrooms where teachers could call on more individual students to read or engage in questions in class, since they had access to the text via the tablets. These teachers described tablet use not only changing the context of learning in their schools by redefining students' orientation to school—potentially because of the status associated with learning via technology in these settings—but also as augmenting prior classroom practices by facilitating communication and improving access to course materials. Here we share excerpts from two classroom observation vignettes that illustrate these enhanced interactions:

> The teacher called on more than 20 students to read from the eReader. He paused them if they were having trouble pronouncing a word or reading punctuation correctly and would either correct the student or ask the class to correct the student. The teacher would then have that student continue (sending message that it was okay to struggle). The teacher paused to adjust the font size for a student having difficulty. When asking comprehension questions, the teacher holds students accountable to providing text-evidence by asking students to provide the page number and paragraph for where they found their answer [in the eReader]. 42 e-Readers were charged, so most students had one they could refer to, giving them the opportunity to use it for their individual needs (font size, looking up vocabulary words they did not understand, etc.).

> The teacher has a very good rapport with students. There are many opportunities for participation and quality learning/critical thinking. The teacher takes extra time at the beginning of class to make sure students are on the correct page and that everyone has access to an eReader at their bench (even if they must share with 4 other students). The teacher uses every opportunity he can to have students engaging with the eReader by asking them to read the vocabulary words, read the practice sentences, come up with their own sentences, and work independently, so that students are talking almost the same amount of time as the teacher.

The increased access to educational resources and improved student engagement identified in classroom observations and noted by teachers were consistent with greater improvements in oral reading fluency and reading comprehension (in Kiswahili and English) observed among eReader users compared to students in classrooms without eReaders. Our (value-added) regression analysis of the student performance from the baseline to end line assessments shows that students in classrooms with eReaders consistently realized larger increases in academic performance; however, only about one-third of the differences were statistically significant. Table 2 summarizes the regression results, presenting the coefficient estimates for the treatment (eReader) indicator for each of the academic performance measures for the two model specifications (Equations 1 and 2)—separately with pretreatment controls only (for baseline academic performance) and including all controls shown in Table 1—while also adjusting for student clustering in classrooms.

The estimated improvements in oral reading fluency and comprehension are larger (and more often statistically significant) for English reading skills. Controlling for student characteristics also increases the magnitude of the estimated differences. These findings are consistent with student comments in focus groups, who self-reported improved grades that they attributed to the tablets, while others cited higher rankings on national exams. Teachers also reported better academic performance among students after receiving eReaders, citing improved and faster reading ability as well as higher achievement in writing, math and science.

Table 2: Estimated changes in student's academic performance associated with eReader use (value-added regression analysis results)

	Pretest control only			*All controls*		
Dependent variable	*N*	*Coefficient*	*Robust std. error*	*N*	*Coefficient*	*Robust std. error*
Changes in academic performance from baseline to end line (1)						
Δ in Kiswahili correct words per minute	222	**16.539**	8.502	218	**19.027**	6.256
Δ in English correct words per minute	198	**23.206**	7.913	197	**25.275**	6.236
Δ in Kiswahili comprehension	222	0.918	0.542	218	0.726	0.435
Δ in English comprehension	222	0.883	0.504	218	0.401	0.420
Δ in Kiswahili comprehension (incorrect)	222	−0.807	0.594	218	−0.656	0.504
Δ in English comprehension (incorrect)	222	−0.725	0.494	218	−0.507	0.510
Predicting end line academic performance (2)						
Kiswahili correct words per minute	222	1.923	2.265	218	2.636	2.946
English correct words per minute	198	7.640	4.026	195	6.309	6.481
Kiswahili comprehension	222	0.260	0.202	218	0.069	0.228
English comprehension	222	**0.763**	0.187	218	**1.054**	0.322
Kiswahili comprehension (incorrect)	222	−0.423	0.340	218	0.074	0.208
English comprehension (incorrect)	222	**−0.834**	0.213	218	**−0.878**	0.328

Note Estimated effects (coefficients) in boldface are statistically significant at $\alpha = .05$.

Challenges to successful technology integration

Despite promising shifts in students' educational experiences in classrooms with eReaders, several barriers to effective integration limited the extent to which the full potential of eReader use was realized. One of the most pressing concerns raised by teachers was limited access to electricity and related challenges keeping tablets charged. Some, but not all schools, reported access to a generator. Teachers from other schools traveled long distances to charge the tablets at one of the other schools or charged the tablets at their personal residences. While the Kenyan government continues to support rural electrification efforts, further investments in basic infrastructure and the equitable distribution of tablets across all schools will be needed to reduce between-school disparities in tablet access.

In addition to charging issues constraining the number of tablets available on a given day, we only observed a one-to-one student to the tablet ratio in 32 percent of the classroom sessions. This limited the ability of students to take full advantage of features that facilitated personalized learning, such as adjusting the font size to improve the readability, working at one's own pace and taking the tablet home. At the same time, we observed that the device sharing could facilitate peer-to-peer learning and collaboration, indicating that a one-to-one ratio was not a *necessary* condition for learning with the tablets. In fact, Haßler, Major, and Hennessy (2016) suggest that with the high relative advantage tablets provide many low-resource settings, targeting a one-to-one student to device ratio may not be the best use of limited resources. Instead, the same funds may be better used to enhance the professional development for teachers on device use and integration (Haßler *et al.*, 2016). Indeed, it would have been advantageous to offer more professional training to the rural Kenya teachers on how to leverage tablets for multiple learners working on a single device. The increased use of peer-to-peer learning and collaboration marked one of the most notable deviations from teacher-directed, lecture-based instruction observed in most classrooms. The resulting opportunities for the student agency represent a partial redesign of instructional processes in a manner that began to transform relational dynamics and academic expectations in the classroom.

Beyond the opportunities for peer collaboration facilitated through device sharing, the introduction of eReaders was not combined with concerted efforts to assist teachers in transforming instructional practices to be more student-centered. Regardless of the eReader access, most lessons still consisted of teachers copying notes onto the board, teachers lecturing about the notes and students copying the notes or practice questions into their exercise books. It was relatively rare to observe teachers engaging with students (or interacting with the tablets) in a manner that invited student dialogue. Reflecting cultural norms, teachers' seldom asked students to demonstrate their understanding of the skills being taught until the very end of the lesson (on their homework, checked by teachers after the class). The general lack of (SAMR) transformative practice using the tablets highlights the importance of pedagogical as well as technological knowledge, per TPK intersection (Mishra & Koehler, 2006). This reflects not only a human (instructional) capacity limitation but also the challenge of transforming and reimaging pedagogical practices in any institutional setting—regardless of the tools available—when doing so runs counter to cultural norms and practices. This excerpt from a classroom observation vignette is illustrative of typical pedagogical practice:

> The teacher reviewed the previous lesson and then clearly stated that the heading students should be on for the new subtopic and walked around to make sure students were there. Most of the rest of the lesson consisted of the teacher walking through the topic and lecturing with his paraphrases from eReader notes, and then asking students to tell him answers to questions he asks using the eReaders. Some students who struggle with English have a hard time following because they are not given time to read.

The above excerpt also points to the lack of accommodation for students at different levels of learning. Further, due to overall high student–teacher ratios, many teachers relied on student technology expertise to resolve technical issues, resulting in differential access to reading material. In the absence of options to provide accommodations on the eReaders, teachers often excluded students experiencing academic challenges (or "slow learners" as teachers described them). Teachers reported that "slow learners" experienced more difficulties using the eReaders. One teacher specifically stated, "We don't have enough time in a lesson to help every pupil access (the eReader), so slow learners cannot use eReaders during lessons. If you go one by one to teach them how to open a page, the lesson will be over." The respect accorded to teachers as givers of knowledge and the belief that students were responsible for their own learning in the instructional settings limited the tablet access of students classified as "slow learners." In this way, the tablet use may have exacerbated, or at the very least replicated, existing the stratification based on the ability.

While some teachers made the effort to support every student in using the eReaders, this was not the case in all classrooms. Some teachers paired students' struggling with the eReaders with students perceived as higher performing. This type of pairing provided learning opportunities for both the student providing and the student receiving supports. In addition, a few teachers mentioned that tutorials or reading clubs were designed to support students who struggled both in reading and with the eReader manipulation; however, observations at the schools revealed that only one school held reading club meetings regularly. Greater support and ongoing professional development for teachers in these and similar programs might have facilitated greater tablet access for students with lower reading levels and technical competencies.

Research and policy implications

Findings demonstrating enhanced learning opportunities and more engaging educational experiences represent preliminary but promising evidence of the potential for eReaders to increase student literacy and academic performance in contexts such as rural Kenya. At the same time, challenges in implementation across settings that are exacerbated in low-resource contexts suggest that the success of technology integration in transforming student learning is contingent on responsiveness to local capacity needs (eg, infrastructure), support for transforming pedagogical practice with technology and cultural factors that shape teacher–student interactions around eReaders (Cuban, Kirkpatrick, & Peck, 2001; Rogers, 2003). Specifically, the importance of cultural norms and practices should not be underestimated when anticipating the extent to which tablet use may be leveraged to transform, rather than merely enhance, current instructional practices. Our research also highlighted several policy levers and school-based strategies likely to improve equitable access to quality learning experiences considering persistent infrastructure challenges within this and other similar contexts.

Developing and implementing a successful educational technology initiative requires an ongoing administrative commitment to supporting and leveraging resources, including a base level of infrastructure (eg, a consistent power source), access to general technical knowledge and professional development for pedagogical practice. In low-resource contexts such as rural Kenya, this may require external support such as that provided by the LCA in this study. School leadership often also plays a role in supporting the development and success of supplemental programs, such as tutorials and reading clubs that may increase and enhance the use of eReaders. Where reliable Internet access is not available, access to preloaded educational resources may be a feasible alternative for expanding learning opportunities (Wang, 2016). Additionally, the availability of additional devices to support a one-to-one student to the device ratio could promote greater intensity

of use, as well as opportunities for more personalized and out-of-school learning. However, in settings such as rural Kenya where the relative advantage of devices is high, even when shared, the benefits of reducing the student to device ratio must be weighed against potential advantages of other investments, such as expanding professional development on device integration (Haßler *et al.*, 2016). In fact, device sharing can serve as an impetus to begin transforming instructional practices in a manner that embeds students with greater agency through peer-to-peer learning and collaboration, in contrast to teacher-directed, lecture-based instruction.

Observations of ICT integration in classrooms also highlighted opportunities for this type of peer-to-peer learning and exchange (both among teachers and students) to improve technical knowledge and pedagogical practice with device use and reduce technical issues. Building shared capacities among teachers may also increase the timeliness of support for ICT integration, which, in combination with ongoing professional development, is critical to ensure both quantity and quality of instructional time. This also has implications for classroom management, student engagement and teacher availability to support learning, as well as student academic outcomes (Boschman, McKenney, Pieters, & Voogt, 2016). Recognizing and drawing on students' technical skills in a similar manner can also have the added benefit of encouraging teamwork and fostering student enthusiasm for technology use (Ciampa, 2014). The advantages of peer learning should be balanced; however, with potential equity concerns, so that the teaching and learning of more technically proficient students is supported as well and not deprioritized in the process.

Across classrooms, equity in access to educational technology and its effective use was a persistent concern, but our research suggests that schools and teachers have levers at hand for better engaging and supporting those in need. Indeed, an important benefit of increased access to educational technology in low-resource settings is the opportunity it affords teachers to allocate more time to work directly with students (Ferrer, Belvis, & Pàmies, 2011). Our work also shows that concerted effort is needed to ensure that this most valuable educational resource, the instructor's attention, is equitability distributed in ways that discourages the emergence of within-classroom tracks with differential access to quality learning experiences, such as some teachers' disregard of "slow learners" in the classroom. In our study, some observed strategies for addressing technical challenges, such as tablet sharing and assigning peers to mentor other students on technology use, could also increase or decrease students' ability to benefit from technology access, depending on the implementation.

Our findings on student engagement and performance in classrooms where tablets were integrated strengthen the emerging evidence base that suggests with sufficient support and resource allocations that educational technology has the potential to be instrumental in enhancing learning opportunities. This, in turn, can lessen education and digital divides for students in low-resource settings across the globe. However, continued emphasis must be placed on designing, implementing and supporting initiatives in a manner that minimizes barriers to effective use and ensures equitable access across and within classroom settings.

Statements on open data, ethics and conflict of interest

The data used in these analyses are available in a Stata file upon request from the corresponding author, Carolyn Heinrich: carolyn.j.heinrich@vanderbilt.edu.

This study was reviewed and approved by the Vanderbilt University IRB, protocol # 162045 "Lwala e-Reader Evaluation."

There was no conflict of interest in conducting the research presented in this manuscript.

Acknowledgements

We thank Mr. Jaime Davila and Vanderbilt University for financial support of this research. We also thank the school principals and teachers in Dallas Independent School District and in North Kamagambo, Kenya who opened their classrooms to observation by the research team and participated in interviews. We also greatly appreciate the Jiv Daya Foundation and the Lwala Community Alliance (LCA) for their partnership in this research effort, including the support provided by staff in data collection and other contributions to the research: Esmeralda Garcia-Galvan, Christi Kirshbaum and Christopher J. Ryan, and LCA staff Staci Sutermaster, Joseph Starnes and Liz Chamberlain.

References

Boschman, F., McKenney, S., Pieters, J., & Voogt, J. (2016). Exploring the role of content knowledge in teacher design conversations. *Journal of Computer Assisted Learning*, *32*(2), 157–169. https://doi.org/10.1111/jcal.12124

Buabeng-Andoh, C. (2012). Factors influencing teachers' adoption and integration of information and communication technology into teaching: A review of the literature. *International Journal of Education and Development using Information and Communication Technology*, *8*(1), 136–155.

Burch, P., Good, A., & Heinrich, C. J. (2016). Improving access to, quality, and the effectiveness of digital instruction in K-12 education. *Educational Evaluation and Policy Analysis*, *38*(1), 65–87. https://doi.org/10.3102/0162373715592706

Chetty, R., Friedman, J., & Rockoff, J. (2014). Measuring the impacts of teachers I: Evaluating bias in teacher value-added estimates. *American Economic Review*, *104*(9), 2593–2632.

Ciampa, K. (2014). Learning in a mobile age: an investigation of student motivation. *Journal of Computer Assisted Learning*, *30*(1), 82–96. https://doi.org/10.1111/jcal.12036

Cuban, L., Kirkpatrick, H., & Peck, C. (2001). High access and low use of technologies in high school classrooms: Explaining an apparent paradox. *American Educational Research Journal*, *38*(4), 813–834. https://doi.org/10.3102/00028312038004813

Darling-Aduana, J., & Heinrich, C. J. (2018). The role of teacher capacity and instructional practice in the integration of educational technology for emergent bilingual students. *Computers & Education*, *126*, 417–432.

Ferrer, F., Belvís, E., & Pàmies, J. (2011). Tablet PCs, academic results and educational inequalities. *Computers & Education*, *56*(1), 280–288. https://doi.org/10.1016/j.compedu.2010.07.018

Gyamfi, S. A. (2016). Identifying Ghanaian pre-service teachers' readiness for computer use: A Technology Acceptance Model approach. *International Journal of Education and Development using Information and Communication Technology*, *12*(2), 105–122.

Haßler, B., Major, L., & Hennessy, S. (2016). Tablet use in schools: A critical review of the evidence for learning outcomes. *Journal of Computer Assisted Learning*, *32*(2), 139–156. https://doi.org/10.1111/jcal.12123

Herodotou, C. (2018). Young children and tablets: A systematic review of effects on learning and development. *Journal of Computer Assisted Learning*, *34*, 1–9.

Hilton, J. T. (2016). A case study of the application of SAMR and TPACK for reflection on technology integration into two social studies classrooms. *The Social Studies*, *107*(2), 68–73.

Hohlfeld, T. N., Ritzhaupt, A. D., Barron, A. E., & Kemker, K. (2008). Examining the digital divide in K-12 public schools: Four-year trends for supporting ICT literacy in Florida. *Computers & Education*, *51*(4), 1648–1663.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017–1054.

Mndzebele, N. (2013). Challenges faced by schools when introducing ICT in developing countries. *International Journal of Humanities and Social Science Invention.*, *2*(9), 1–4.

Nasir, N. S., & Hand, V. M. (2006). Exploring sociocultural perspectives on race, culture, and learning. *Review of Educational Research*, *76*(4), 449–475.

Orlikowski, W. J. (2000). Using technology and constituting structures. *Organization Science*, *11*(4), 404–428.
Orlikowski, W. J., & Gash, D. C. (1994). Technological frames: Making sense of information technology in organizations. *ACM Transactions of Information Systems*, *2*(2), 174–207.
Pelgrum, W. J. (2001). Obstacles to the integration of ICT in education: Results from a worldwide educational assessment. *Computers & Education*, *37*(2), 163–178.
Puentedura, R. (2013). *SAMR: A contextualized introduction*. Retrieved from http://www.hippasus.com/rrpweblog/archives/000112.html
Richardson, J. W. (2011). Challenges of adopting the use of technology in less developed countries: The case of Cambodia. *Comparative Education Review*, 55(1), 8–29. https://doi.org/10.1086/656430
Rogers, E. M. (2003). *Diffusion of innovations*. New York, NY: Simon & Schuster.
Rogoff, B. (2003). *The cultural nature of human development*. Oxford, UK: Oxford University Press.
Stanhope, D. S., & Corn, J. O. (2014). Acquiring teacher commitment to 1: 1 initiatives: The role of the technology facilitator. *Journal of Research on Technology in Education*, *46*(3), 252–276.
Stols, G., Ferreira, R., Pelser, A., Olivier, W. A., Van der Merwe, A., De Villiers, C., & Venter, S. (2015). Perceptions and needs of South African mathematics teachers concerning their use of technology for instruction. *South African Journal of Education*, *35*(4), 1–13.
Tamim, R. M., Borokhovski, E., Pickup, D., & Bernard, R. M. (2015). Large-scale, government-supported educational tablet initiatives. *Commonwealth of Learning*. https://doi.org/10.13140/RG.2.1.2359.7849
Twining, P., Raffaghelli, J., Albion, P., & Knezek, D. (2013). Moving education into the digital age: The contribution of teachers' professional development. *Journal of Computer Assisted Learning*, *29*(5), 426–437. https://doi.org/10.1111/jcal.12031
Venezky, R. L. (2004). Technology in the classroom: Steps toward a new vision. *Education, Communication & Information*, *4*(1), 3–21. https://doi.org/10.1080/14636310420002110 24
Warschauer, M., & Matuchniak, T. (2010). New technology and digital worlds: Analyzing evidence of equity in access, use, and outcomes. *Review of Research in Education*, *34*(1), 179–225.
Warschauer, M., Knobel, M., & Stone, L. (2004). Technology and equity in schooling: Deconstructing the digital divide. *Educational Policy*, *18*(4), 562–588.
Wang, Y. H. (2016). Could a mobile-assisted learning system support flipped classrooms for classical Chinese learning? *Journal of Computer Assisted Learning*, *32*(5), 391–415. https://doi.org/10.1111/jcal.12141
Wong, E. M. L., Li, S. S. C., Choi, T.-H., & Lee, T. N. (2008). Insights into innovative classroom practices with ICT: Identifying the impetus for change. *Educational Technology & Society*, *11*(1), 248–265.

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.