International Journal of Educational Development 49 (2016) 204–214

Contents lists available at ScienceDirect

International Journal of Educational Development

journal homepage: www.elsevier.com/locate/ijedudev

Does technology improve reading outcomes? Comparing the effectiveness and cost-effectiveness of ICT interventions for early grade reading in Kenya

Benjamin Piper[a,*], Stephanie Simmons Zuilkowski[b], Dunston Kwayumba[c], Carmen Strigel[d]

[a] RTI International, Nairobi Regional Office, The Westwood, 5th Floor, Vale Close, Ring Road Parklands, P.O. Box 1181 Village Market, 00621 Nairobi, Kenya
[b] Florida State University, Center for International Studies in Educational Research and Development, Learning Systems Institute, University Center C4600, P.O. Box 3062540, Tallahassee, Florida 32306-2540, United States
[c] RTI International, Nairobi Regional Office, The Westwood, 5th Floor, Vale Close, Ring Road Parklands, P.O. Box 1181 Village Market, 00621 Nairobi, Kenya
[d] RTI International, 3040 East Cornwallis Road, P.O. Box 12194, Research Triangle Park, NC 27709-2194, United States

ARTICLE INFO

Article history:
Received 17 March 2015
Received in revised form 14 January 2016
Accepted 14 March 2016
Available online 4 April 2016

Keywords:
Literacy
International education
Technology
Reading
Education policy
Kenya

ABSTRACT

Education policymakers are investing in information and communications technology (ICT) without a research base on how ICT improves outcomes. There is limited research on the effects of different types of ICT investments on outcomes. The Kenya Primary Math and Reading (PRIMR) study implemented a randomized controlled trial comparing the effects and cost of three interventions – e-readers for students, tablets for teachers, and the base PRIMR program with tablets for instructional supervisors. The results show that the ICT investments do not improve literacy outcomes significantly more than the base non-ICT instructional program. Our findings show that cost considerations should be paramount in selecting ICT investments in the education sector.

1. Introduction

The global Education for All movement has been successful by some indicators – improving access for primary-age children, for example – and a failure by others. In many countries, including Mali, Uganda, and the Gambia, more than half of children are still nonreaders at the end of second grade (Dubeck and Gove, 2015; Gove and Cvelich, 2011). This is a crisis at both the individual and national levels. Low literacy outcomes are associated with school dropout over time (Marteleto et al., 2008), and youth with limited schooling are less likely to have occupational outcomes other than farming occupations as adults (Winters et al., 2009). Recent research suggests that literacy skills are related to economic growth at the national level (Hanushek and Woessmann, 2012). Keeping children in schools where they do not learn literacy skills – or anything of pedagogical value – is, therefore, a waste of resources from a national development perspective. Accordingly, many international educational initiatives have shifted their focus from programs and policies related to education access toward those that also aim to improve quality.

As mobile devices become cheaper and access more widespread, many policy makers, educators, and researchers have looked to technology as a means of addressing these quality issues. In low-resource settings, mobile devices can increase the amount of text children are exposed to and support the scaffolding of poorly trained or untrained teachers. Mobile technology allows for individualized learning, even in contexts where large classes are the norm (Grace and Kenny, 2003). Content can easily be provided digitally in multiple languages, whether national languages or mother tongues (Wagner, 2014), thereby avoiding the costs associated with printing small runs of language-specific textbooks. With appropriate software, teachers can carry out continuous assessments to improve instruction and give immediate feedback on student performance, providing tailored support where needed. In the longer run, exposure to technology can contribute to the skills that children will need for jobs in the future (Grace and Kenny, 2003). Even children without previous experience using mobile devices can quickly pick up the skills needed to play

* Corresponding author.
E-mail addresses: bpiper@rti.org (B. Piper), szuilkowski@lsi.fsu.edu (S.S. Zuilkowski), dkwayumba@tusome.rti.org (D. Kwayumba), cstrigel@rti.org (C. Strigel).

http://dx.doi.org/10.1016/j.ijedudev.2016.03.006

learning games (Kim et al., 2012). These potential benefits have resulted in many pilot projects in developing countries, but little robust research on the effects of these projects on learning outcomes to guide stakeholders in determining policies or designing large-scale programs.

This paper aims to begin to fill this gap by examining the potential of ICT interventions to improve literacy within early grade classrooms in Kenya. Within the context of the Primary Math and Reading (PRIMR) Initiative, a randomized controlled trial,[1] we compare the effects on learning outcomes – in one particular county – of three PRIMR interventions: student e-readers, teacher tablets, and the base PRIMR intervention with tablets for government-funded instructional supervisors, who are called TAC tutors in Kenya.[2] We then use a cost-effectiveness lens to examine those outcomes. Finally, using data from assessments measuring Grade 2 students' skills in literacy at baseline and endline assessments, we compare the impact of the three ICT intervention groups with the results of the base PRIMR program as implemented in other parts of Kenya. This approach provides evidence not only of value-added effects of an ICT intervention built onto a successful literacy intervention, but also of which levels of intervention are likely to have the greatest effect in low-resource settings such as Kenya.

2. Background

2.1. ICT literacy interventions

As access to mobile phones and other portable electronic devices spreads throughout the world, the number of interventions attempting to use these devices to enhance learning for people of all ages is increasing dramatically. Ten years ago, examining programs using forms of technology that were current at the time, a World Bank report noted that there was little evidence on the effectiveness and cost-effectiveness of ICT interventions, and the few studies that existed found mixed results (Trucano, 2005). In the decade since, the cost of laptops, tablets, and smartphones has decreased sharply, increasing their viability as scalable tools in low-resource settings, and the evidence base on their effectiveness in classrooms and schools is beginning to develop. A recent review of a broad range of interventions to improve learning in developing countries found that, across 15 technology-based interventions, the average effect size was a modest 0.15 standard deviations (SD) (McEwan, 2014). Because not all of these interventions were successful, more detailed comparative research into the features of such programs – whether they succeeded or failed – may be a useful next step.

Before moving to the analysis of the PRIMR research, we begin with a literature review focusing on a narrow set of studies – those examining the use of ICT applications in early grade classrooms in developing countries for the enhancement of literacy instruction and outcomes. Two possibilities exist that would support the use of technology in classrooms: (1) that it is cheaper than alternative approaches of teaching the material, or (2) that it is more effective, with the benefits resulting in greater cost effectiveness. However, little robust evidence has been produced that speaks to these two points (Wagner, 2014). Among the 44 mobile literacy projects reviewed by Wagner, only eight (i.e., 18%) had conducted a formal evaluation of any type, and just one a randomized controlled trial.

The current body of research underlines that technology must be integrated into an effective learning program in order for it to have an impact on students. In Peru, a randomized controlled trial of the One Laptop Per Child program found that, while children's access to and usage of computers increased, there were no statistically significant effects on math or language scores (Cristia et al., 2012). The authors concluded that "governments should consider alternative uses of public funds before implementing large-scale technology in education programs" (p. 20). However, in the Peru intervention, the software was not tailored to pedagogical or curricular needs, and students spent much of their time using word processing and other basic tools, playing games, and listening to or recording music. That study, therefore, does not directly answer the question of whether a technology program might be effective when built on top of, and in direct support of, a high-quality literacy program. This misalignment between the goals of ICT programs and the tools' actual use in the classroom is common (Trucano, 2005).

In urban Zambia, researchers tested a Nyanja literacy game with urban first-graders using a randomized controlled trial (Jere-Folotiya et al., 2014). The authors found the greatest effects in spelling in the intervention groups in which the students and teachers all played the game and teachers were trained in a compatible phonics-based approach. This study supports the hypothesis that ICT applications can be effective for literacy *if* they are well-aligned with an underlying pedagogic intervention. But the study did not compare the relative effectiveness of various ICT applications and hardware choices that might be available to policy makers.

A study using e-readers with 481 students in Ghana had positive effects on fourth-grade students' reading scores, particularly when the children received support through an after-school program (ILC Africa and Worldreader, 2012). However, 40% of the e-readers broke during a seven-month period, which the implementers believed was due to the devices not being durable enough to handle the dust and other environmental issues.[3] The program was popular with students and teachers despite these implementation issues, and students who received the e-readers often shared them with family members and friends, thereby creating a multiplier effect.

ICT interventions may have differential effects for certain groups of students. For example, there is some evidence that mobile literacy applications work better for children who already have stronger literacy skills before the intervention. As an example, the Mobile and Immersive Learning for Literacy in Emerging Economies (MILLEE) program developed literacy games for use on mobile phones in the context of an English after-school program in Uttar Pradesh, India (Kam et al., 2009). Participants were prescreened with a simple English test requiring them to exhibit their ability to write simple sentences. There was a statistically significant association between pretest score and gain score, with the students with stronger skills gaining more over the course of the program. Children may also face differences in ICT device access and usage by gender or socioeconomic status, although the limited amount of rigorous data available makes conclusions regarding this supposition impossible at this point. Though ICT applications have the potential to be adaptive for students with visual, hearing, physical, or developmental disabilities (Wagner et al., 2005), they have not typically been designed for such usage in interventions in sub-Saharan Africa.

Even when technology use is relatively intensive, teachers remain the core of the education system. Teachers must be

[1] PRIMR's period of performance was 2011–2014; additional program details are presented in a later subsection.

[2] TAC tutors operate from within the Teachers' Advisory Centre (TAC), a unit of the Teachers' Service Commission. In 2016, the title was formally changed to "Curriculum Support Officer."

[3] Worldreader, one of the implementers of the study, has since increased usage and care education in its programs, as well as worked with hardware suppliers to increase the durability of its e-readers. A recent report indicated that breakage rates had fallen below 10% (Worldreader, 2013).

supported in planning lessons that make use of the technology in a productive way (Trucano, 2005); the availability of technology does not necessarily lead to changes in teacher behavior without accompanying training and an overall theoretical approach designed to improve learning (Cristia et al., 2012; Wagner et al., 2005). While ICTs can enhance teacher motivation, they can also be a source of stress for those who are new to the technology (Trucano, 2005), and this stress may result in less effective teaching overall. However, in Ghana, teachers reported that having current textbooks and materials on an e-reader made it easier for them to plan (ILC Africa and Worldreader, 2012), suggesting that sufficient training can help to overcome initial teacher reservations.

The studies discussed above, including the broad review carried out by Wagner (2014) of the range of programs being implemented in Africa and Asia, make clear that ICTs cannot stand alone as the solution to the developing world's challenges in education quality. It is important to acknowledge that "social practices" are part of the equation (Roschelle, 2003). That is, technology may change relationships between and among students and teachers in ways that are unintended. As proposed by Wagner (2014), mobile learning approaches will be most successful when they combine appropriate devices, are designed with the end users in mind, and are focused on a specific purpose. These factors are all influenced by the context in which the program is situated (see Fig. 1). Wagner's (2014) model extends previous research because it requires researchers to examine the interplay among the devices chosen, the end users to be affected, and the purposes of the program, within a particular context. Our analysis of the literature found very few rigorous studies that examined all three of these factors, and even fewer that did so within the sub-Saharan African context.

2.2. Context

Kenya's Free Primary Education initiative has been successful in ensuring that children have the opportunity to attend school. Gross primary enrollment rates are now above 100% (United Nations Educational, Scientific and Cultural Organization (UNESCO), 2014). Student performance has been poor, however, especially on tests of Kiswahili and English literacy in the early grades. The Ministry of Education, Science, and Technology (MoEST) has set national reading fluency benchmarks for Grade 2 of 65 correct words per minute (cwpm) for English and 45 cwpm for Kiswahili. Similar benchmarks for *emergent* fluency were set at 30 cwpm for English and 17 cwpm for Kiswahili. In the baseline assessment for the ICT study, the researchers found that Grade 2 students read on average only 9.3 cwpm in English and 8.9 cwpm in Kiswahili. These results aligned with those from a number of previous studies in which Kenyan students failed to demonstrate grade-appropriate reading skills (Mugo et al., 2011; Onsomu et al., 2005; Wasanga et al., 2010).

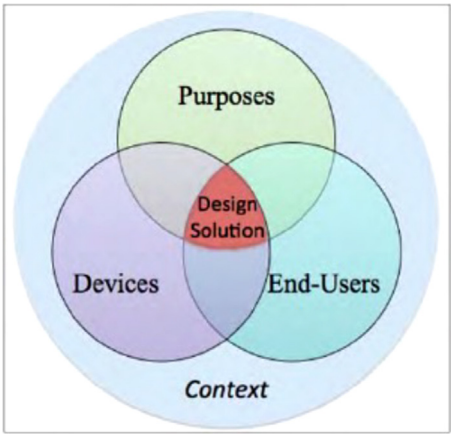

Fig. 1. ICT program design solution as a function of purposes, devices, and end users.
Source: Wagner (2014).

PRIMR's ICT study was implemented in Kisumu County, a diverse county in the western part of Kenya. Fishing, agriculture, and light industry are the primary occupations. The Luo are the major ethnic group, and the predominant mother tongue is Dholuo. This means that children in primary schools are learning in, at best, their second and third languages (Kiswahili and English), as the language-of-instruction policy of using mother tongue is very seldom followed (Piper and Miksic, 2011).

2.3. The Primary Math and Reading Initiative (PRIMR)

As noted, the ICT intervention evaluated here was built on the base PRIMR program funded by USAID, which was implemented in 370 schools and had four central components, none focused specifically on ICT. An expansion of the PRIMR program, funded by the UK Department for International Development (DFID), was implemented in 834 public primary schools in rural locations. The PRIMR program, whether funded by DFID or USAID, provided teacher and head teacher training in literacy and numeracy for 10 days per year, including an initial five-day training and two refresher sessions; low-cost, full-color books for every child at a 1:1 ratio; teachers' guides that matched closely with the content in the student book; and ongoing instructional support for teachers on the key elements of instruction most strongly correlated with learning achievement. In addition to these key components, an engaged and active MoEST encouraged its instructional supervisors, the TAC tutors, to consistently visit classrooms and provide instructional feedback through a coaching model (Piper and Zuilkowski, 2015). This full package of interventions led to effect sizes ranging from 0.2 to 0.5 SD for literacy outcomes in English and Kiswahili in the base, non-ICT PRIMR program (Piper, Jepkemei et al., 2015; Piper et al., 2014). The base PRIMR program had already been in place for one year at the commencement of the ICT trial in Kisumu County.

This randomized controlled trial design compared the outcomes from a control group with the relative effectiveness of the base PRIMR program (which included a modest TAC tutor tablet component) as well as two more intensive ICT interventions, one of which added tablets for teachers and the other of which incorporated e-readers for students. The three interventions are discussed in detail below.

The PRIMR ICT program in Kisumu County was designed to capitalize on the interest and engagement of the MoEST about ICT. The 2013 academic year coincided with the electoral promise of the new Jubilee coalition government to provide laptops at a 1:1 ratio for all Grade 1 children in the country. During the period in question, MoEST policy makers had heightened interest in ICT, and they perceived the PRIMR ICT program as being an important precursor to the larger-scale laptop program. The three technology options tested in this study were proposed rather than laptops due to their lower cost and ease of use.

3. Research questions

Based on the gaps in the literature relating to our understanding of what impact ICT can have on learning outcomes, how choices in hardware and software influence learning outcomes, and how the cost of ICT interventions relates to learning outcomes, we chose to address the following research questions:

RQ1: Which of the three treatments was the most effective?

RQ2: Which of the three treatments was the most cost effective?

RQ3: How did the treatment effects compare to the base PRIMR program implemented elsewhere in Kenya?

4. Research design

In this section we present details about the research design of the PRIMR ICT study.

4.1. Treatment groups

The three treatment groups were as follows.

In the **PRIMR + TAC tutor tablet group**, the intervention was essentially the same as the base PRIMR program. It included the same amount of teacher training, instructional support, and student learning materials at a 1:1 ratio. In addition, this treatment gave two officers tablets to support teachers in their instruction. That is, the TAC tutors in two zones, one peri-urban and one rural, were given a tablet that contained materials to improve the quality of their instructional support to teachers. This included electronic versions of the teachers' guides for the TAC tutors to follow as they conducted classroom observations; electronic versions of the student books, to cut down on the heavy load that many TAC tutors physically carried during the implementation of the PRIMR program; and instructional support tools that supplemented those PRIMR-specific items. The content included all student and teacher materials that were on the teacher tablet (see next paragraph) in addition to materials that were designed exclusively for the TAC tutors. Such materials included guidance on specific pedagogical challenges in Kenyan classrooms. The TAC tutors' ability to consistently use the tablets for instructional support was uneven, and one of the two TAC tutors assigned to the PRIMR + TAC tutor treatment group struggled to use the technology effectively. This treatment group was, in short, the base PRIMR program implemented in two zones of Kisumu County.

In two other zones, one peri-urban and one rural, all Grade 2 teachers in the **PRIMR + teacher tablet group** were provided with a tablet to scaffold their literacy instruction. The tablet contained multimedia lesson plans that matched the base PRIMR paper-based lessons, but also had embedded audio files for letter sounds and word reading; supplementary pedagogical aids, including letter flashcards and an application called Papaya™, designed for letter-sound practice for teachers struggling to differentiate letter sounds in English and Kiswahili; and the Tangerine:Class™ application, which was a sophisticated classroom feedback mechanism. Teachers were guided on tablet-based assessments to give their students, based on where they were in the PRIMR materials, and then the Tangerine:Class program analyzed the results and gave teachers suggested feedback on what to reteach and which pupils needed more help. A recent study on the Tangerine:Class program showed that the PRIMR + teacher tablet intervention had carefully scaffolded training and follow-up support, and that teachers preferred to teach from the tablet than from the typical book-based lesson plans (Strigel et al., 2015). Success in this ICT component relied on the teachers' ability to manipulate the tablet as well as their skill in using the content therein. Teachers varied widely in their frequency of using the tablets for lessons, with some teachers implementing the lessons with fidelity, and others only infrequently utilizing the PRIMR methods. With respect to the use of the Tangerine:Class software, few of the teachers used the tool consistently (Strigel et al., 2015), although the teachers spoke positively about the power of the tool's ability to provide nuanced feedback on learning (Piper and Kwayumba, 2014).

Lastly, in the **PRIMR + pupil e-readers** group, Grade 2 students and teachers in two zones, one peri-urban and one rural, were provided with individual e-readers. These e-readers contained the base PRIMR reading textbooks in English and Kiswahili in electronic format; relevant textbooks from Kenyan publishers; reading materials in Dholuo, the local language of many in Kisumu County; and hundreds of additional grade-appropriate readers in English, Kiswahili, and Dholuo. The number of books available was expanded during term breaks, such that during the 2013 academic year, each student had access to more than 160 additional readers. During the initial implementation of the program, pupils were allocated afternoon sessions for reading, with teachers nearby available for consultation. By the second term, pupils were allowed to read from home. The e-reader group was supported by Worldreader, which had two full-time staff who showed the teachers how to use the e-readers effectively. With oversight from the Worldreader team, the e-reader school communities managed the e-readers exceedingly well, as less than 2% of e-readers were lost or severely damaged during the entire year of the PRIMR ICT program.

All three treatment designs involved training the TAC tutors supporting the intervention prior to the teacher training. The TAC tutors were shown how to give teachers instructional support using the base PRIMR program or the ICT-enhanced PRIMR program. The TAC tutors in each of the three treatment groups received 15 days of teacher training spread out over the three terms. Teachers participated in a total of 10 days of training led by the TAC tutors, supported by the PRIMR technical teams. The training was distributed over the three terms so that teachers had initial trainings and then refreshers before the second and third terms of the year. For the two ICT treatment groups, the PRIMR teacher and TAC tutor trainings included sessions on the usage of the devices and the software provided, with particular emphasis on the PRIMR methodology in English and Kiswahili. During the refresher trainings, the topics discussed were tailored to each intervention group and designed to address issues observed and

Table 1
Student data collected at PRIMR ICT program baseline and endline.

Treatment group	Sampled zones and schools			Pupils assessed	
	Zone type	Schools per zone	Sampled schools	January 2013 baseline	October 2013 endline
PRIMR + tutor tablet	Peri-urban	16	10	198	198
	Rural	13	10	197	188
PRIMR + teacher tablet	Peri-urban	15	10	200	196
	Rural	18	10	199	199
PRIMR + e-reader	Peri-urban	15	10	200	200
	Rural	15	10	190	193
Control	Peri-urban	15	10	199	200
	Rural	18	10	197	186
Total		135	80	1580	1560

reported during the previous term, to improve English and Kiswahili instruction.

4.2. Sample

As noted, the ICT study used a randomized controlled trial design. The PRIMR team randomly selected 8 zones from the total of 34 zones in Kisumu County. These 8 zones were then randomly assigned to one of the three treatment conditions or the control group, stratified by rural and peri-urban location. Within each zone, 10 primary schools were randomly selected to implement a particular treatment. This resulted in a total of 80 schools involved in the ICT program: 60 intervention schools and 20 control schools. With respect to the baseline and endline assessments in January 2013 and October 2013, respectively, the PRIMR researchers randomly selected 20 Grade 2 pupils from each of the 80 primary schools. Simple random sampling, stratified by sex, was used to sample an equal number of boys and girls in the study at both baseline and endline. The baseline literacy data collection was completed in January 2013, at the start of the school year and before the start of implementation; data collection for the endline study was completed in October 2013. The assessed sample was 1580 students in January 2013 and 1560 students in October 2013 (see Table 1).

4.3. Measures

The instrument used to measure student performance at baseline and endline, for all three ICT treatments, was the Early Grade Reading Assessment (Dubeck and Gove, 2015; Gove and Wetterberg, 2011), adapted for use in Kenya. As in the evaluations of the base PRIMR program, this analysis of the ICT study focuses on the key outcomes of oral reading fluency (ORF), expressed in correct words per minute; and the percentages of pupils reaching the MoEST's benchmarks for reading fluency and comprehension (students were assessed on many other language tasks that are not presented, for parsimony). The instruments used in the ICT impact evaluation had internal consistency results similar to those established for the base PRIMR program implemented elsewhere in Kenya (Piper and Kwayumba, 2014; Piper and Mugenda, 2012).

Data were collected using Tangerine®, an open-source early learning assessment software developed by RTI International to enhance data collection efficiency, assure data quality, and accelerate data availability for analysis. This application had been piloted in Kenya and had since been deployed more than 20 times in 20 different countries by 10 different organizations (RTI International, 2013). Tangerine utilized an automatic timing system, auto-stop functionalities whenever the allocated time ran out on the instruments' timed subtasks, and a stop function that allowed assessors to mark the last items read. Additionally, the application allowed the child to be asked only the questions that corresponded to the percentage of the passage the child had read. The EGRA was conducted by a trained team of assessors, some with more than five years of literacy assessment experience. The average interrater reliability scores for the field data collection team were 96% during baseline and 97% at endline.

Table 2 presents descriptive statistics for English oral reading fluency and Kiswahili oral reading fluency at baseline (January 2013) and endline (October 2013). The results show low fluency rates in both English and Kiswahili at the baseline for all four treatment groups. The results at the baseline showed that the lowest mean fluency rates were found in the teacher tablet treatment group, with the highest in the TAC tutor tablet treatment group. At the endline, the control group had the lowest mean fluency rates in Kiswahili, while the teacher tablet group had the lowest fluency rates in English.

4.4. Data-analytic plan

Despite random assignment of the zones to treatment groups, analysis of the baseline data revealed statistically significant differences in performance among the four groups. Specifically, as noted above, the teacher tablet group's baseline results were lower than those of other groups, including the control group. In order to determine the impact of the treatment, we therefore utilized a difference-in-differences (DID) identification strategy using ordinary least squares (OLS) regression models. DID models compare changes in a program's outcome variables at two different assessment points for treatment and control groups. This allows the analysis to separate program impact from changes in the population not due to program impact (Murnane and Willett, 2011).

A key assumption of the DID model is that the trends in the covariates not related to the intervention will be similar for the treatment and control groups. Table 3 presents the key covariates at the student, teacher, classroom, and school levels. We used regression analysis to estimate whether there were statistically significant differences in these covariates between treatment and control groups. Covariates are presented by treatment group at baseline, and then the differences between the baseline and endline results appear in the column for endline. The covariates presented are the percentage of students who were female; student age; a student wealth index (the total of nine household items that the students identified as having in their home); whether the student attended kindergarten, pre-kindergarten, or other preschool; whether the pupil had the English or Kiswahili books; and whether the child read at home. At the teacher level, we present the average age of the teachers, and the average class size. At the school level, we share head teachers' average years of

Table 2
Grade 2 English and Kiswahili ORF at baseline and endline.

Group	Average correct words per minute, by language and assessment period (standard errors in parentheses)			
	English		Kiswahili	
	Baseline	Endline	Baseline	Endline
Control	8.6	25.3	7.7	16.4
	(0.4)	(1.1)	(0.4)	(0.7)
Pupil e-reader	10.1	36.0	10.0	24.9
	(0.6)	(1.1)	(0.5)	(0.7)
Teacher tablet	5.7	23.9	6.3	18.9
	(0.3)	(0.8)	(0.3)	(0.6)
TAC tutor tablet	15.5	39.7	13.0	26.6
	(0.8)	(1.0)	(0.6)	(0.6)

Note: The Taylor series linearization method was used in calculating the standard errors.

Table 3
Covariates at the school, teacher, classroom, and teacher level at baseline; and differences at endline, by treatment group (standard errors in parentheses).

Covariate	Control		Pupil e-reader		Teacher tablet		TAC tutor tablet	
	Baseline	Endline	Baseline	Endline	Baseline	Endline	Baseline	Endline
Student female (%)	48.5	0.6***	51.3	0.0***	47.6	0.3***	48.3	−0.1***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Student age (years)	8.0	0.0*	8.2	0.1***	8.1	0.1***	8.3	0.0**
	(0.1)	(0.0)	(0.1)	(0.0)	(0.0)	(0.0)	(0.1)	(0.0)
Student wealth index	3.4	0.1*	3.4	0.1**	3.0	0.1***	3.4	0.1***
	(0.1)	(0.0)	(1.0)	(0.0)	(0.1)	(0.0)	(0.1)	(0.0)
Attended kindergarten or pre-K (%)	89.3	1.0**	94.0	0.2	86.7	0.8*	96.0	−0.9**
	(1.3)	(0.3)	(1.3)	(0.3)	(1.4)	(0.3)	(1.2)	(0.3)
Had English book (%)	39.7	1.1	39.4	1.0	32.3	7.0***	30.4	7.0***
	(2.7)	(0.6)	(2.9)	(0.6)	(2.3)	(0.5)	(2.5)	(0.5)
Had Kiswahili book (%)	35.2	0.8	30.7	1.9**	24.3	7.5***	31.0	6.6***
	(2.6)	(0.6)	(2.7)	(0.6)	(2.1)	(0.4)	(2.7)	(0.6)
Reads at home (%)	52.2	1.1	48.5	2.2**	42.5	3.4***	35.7	7.2***
	(2.8)	(0.6)	(2.8)	(0.6)	(2.2)	(0.5)	(2.8)	(0.6)
Teacher age (years)	45.3	−0.0***	41.2	0.1***	41.8	0.2***	43.8	0.1***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Class size (number of students)	53.2	0.2***	41.5	0.8***	42.6	0.1***	52.5	−0.6***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Years as a head teacher (years)	7.6	−0.1***	8.8	−0.3***	8.1	0.2***	7.7	0.1***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
School had water (%)	55.0	2.4***	57.5	0.9***	64.0	−0.9***	75.9	−0.9***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
School had electricity (%)	16.1	4.1***	36.3	1.5***	34.3	−0.6***	24.4	3.8***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

experience, and the percentage of schools reporting having access to regular water sources and to electricity.

Table 3 shows that many items differed very little between treatment groups. All four treatment groups had between 47.6% and 51.3% female students, and the average student age ranged between 8.0 and 8.3 years old. Students had between 3.0 and 3.4 of the household items named in the questionnaire, and between 86.7% and 96.0% of pupils reported attending kindergarten or other preschool. The age and experience of teachers also were minimally different, with average teacher ages between 41.2 and 45.3 years old, and head teachers having between 7.6 and 8.8 years of experience. Differences existed in students' access to English books, with the control group having the highest rate (39.7%) and the TAC tutor tablet group having the lowest rate (30.4%). Similarly, the control group had the highest access to Kiswahili books (35.2%), with the teacher tablet group having the lowest rate (24.3%). The control group had the highest percentage of students reading at home (52.2%) and the TAC tutor tablet group had the lowest percentage (35.7%). Class sizes differed by treatment group, with the control group (53.2 students) and TAC tutor tablet group (52.5 students) having larger classes than the e-reader group (41.5 students) or the teacher tablet group (42.6 students). The TAC tutor tablet group had the highest percentage of schools with water (75.9%) while the control group had the lowest (55.0%). The e-reader group had the highest percentage of schools with electricity (36.3%), with the control group having the lowest (16.1%). The baseline comparisons on these covariates revealed no large systematic differences advantaging one particular treatment group over another.

In order for the DID estimate to be valid, what is important is not simply whether there were differences among the groups at the baseline, but whether the trends in the covariates were similar. The endline columns show the differences in the covariate from the baseline. Our interest was in substantively different trends over time between the treatment groups, because if they existed, it would invalidate the assumptions of the DID analysis. For student gender, age, wealth index, and kindergarten attendance, the results show that none of the changes between baseline and endline was larger than 1% for any of the treatment groups. Similarly, small changes existed for teacher age, class size, and years as a head teacher. Larger differences from baseline to endline existed for the variables related to having an English book, Kiswahili book, and reading at home, particularly for the three treatment groups. This is logical given that these three treatments increased access to learning materials. Larger differences existed for the school having access to water, with the control group increasing by 2.4% while the

Table 4
Differences-in-differences estimates of treatment effects on outcome measures.

Treatment group	Average correct words per minute, by language (standard errors in parentheses)		Percentage of children at benchmark	
	English	Kiswahili	English	Kiswahili
Student e-reader	6.1***	5.5***	12.2***	16.5***
	(1.4)	(1.0)	(2.9)	(3.3)
Teacher tablet	8.5***	5.8***	16.2***	15.9***
	(1.5)	(1.0)	(3.0)	(3.3)
Base PRIMR TAC tutor tablet	9.9***	6.7***	18.3***	17.2***
	(1.7)	(1.1)	(3.4)	(4.0)

Note: The Taylor series linearization method was used in calculating the standard errors.
*** $p < 0.001$.

other treatment groups changed by less than 1%. Access to electricity also increased, with the largest gains experienced by the control group. Both of these indicators could have been affected by the rural electrification program implemented by the Government of Kenya in 2013. These modest differences in the covariate trends suggest that the assumptions of the DID model hold.

5. Findings

5.1. RQ1: Which of the three treatments was the most effective?

To answer our first research question, we fit DID models to compare the ORF results of students in each treatment group with those of students in the control group. We found that all three treatment groups improved statistically significantly more in both English and Kiswahili than the control group. The effects identified over the control group in English were 9.9 words for the base PRIMR TAC tutor tablet group (p-value < 0.001), 8.5 cwpm for the teacher tablet group (p-value < 0.001), and 6.1 cwpm for the pupil e-reader group (p-value < 0.001), as shown in Table 4. Comparisons of Kiswahili scores between the three treatment groups and the control group also followed the same pattern. The largest effect was identified in the base PRIMR TAC tutor tablet group (6.7 cwpm; p-value < 0.001); the teacher tablet effect was 5.8 cwpm (p-value < 0.001), and the e-reader group effect was 5.5 cwpm (p-value < 0.001).

Based on the results, we calculated Cohen's d effect sizes. The effect sizes were largest for the base PRIMR and TAC tutor tablet group (0.29 SD in English and 0.32 in Kiswahili) and lowest for the e-reader group (0.17 SD in English and 0.26 in Kiswahili). The effect sizes for the teacher tablet treatment group were 0.26 SD in English and 0.28 SD in Kiswahili.

We examined whether the PRIMR programs increased the percentages of students meeting the MoEST benchmarks for emergent reading fluency and comprehension. Recall that the emergent-reader benchmarks for Grade 2 were set at 30 cwpm in English and 17 cwpm in Kiswahili. Table 4 presents our findings on the impact of the three treatment groups on the percentage of pupils reading at the emergent reader benchmark. For English, the three groups increased the percentage of pupils reaching this benchmark by 18.3 percentage points (p-value < 0.001) in the base PRIMR TAC tutor tablet group, 16.2 percentage points (p-value < 0.001) in the teacher tablet group, and 12.2 percentage points (p-value < 0.001) in the pupil e-reader group. In Kiswahili, the treatment groups increased the percentages reaching the benchmark (17 cwpm) by 17.2 (p-value < 0.001), 15.9 (p-value < 0.001), and 16.5 percentage points ($p < 0.001$) for the base PRIMR TAC tutor tablet group, the teacher tablet group, and the pupil e-reader group, respectively.

5.2. RQ2: Which of the three treatments was the most cost effective?

The first research question asked whether the three treatments had statistically significant impacts on English and Kiswahili literacy outcomes. For the second research question, we examined the cost effectiveness of each treatment. Examining cost in the context of effectiveness is essential for the field of ICT in education, given the wide variation in costs associated with the many ICT investments available in the sector. To measure the cost effectiveness of the three interventions, we first computed the cost of the base PRIMR program and then added the unit cost of the respective ICT component. The costs of the base PRIMR intervention were the same for all three treatment groups, as they included the cost of pupil books, teachers' guides, teacher training, classroom observations, and TAC tutor training. The base unit cost was therefore a ratio of the total cost for program materials and training divided by the number of pupils. This base cost was US$4.56 for English and Kiswahili, or US$2.28 per pupil per subject, and was the same for the three intervention groups compared here. The cost of a single tablet at the time of purchase was US$200, but to account for the rapidly reducing cost of technology, we utilized US$150 for the purpose of this cost analysis. On the other hand, the e-reader used cost US$70 per e-reader, including accessories such as a protective case. To account for the rapidly reducing cost of e-readers, we utilized $40 as the cost of the e-reader. To determine per pupil costs of the ICT hardware for the TAC tutor tablet group, we divided the ICT portion of the costs by the number of schools in a zone (10) and by the estimated average number of pupils in a class (50). For the teacher tablet group, we divided the cost by the average number of pupils in a class (50). In the TAC tutor tablet group, the technology component added US$0.10 per pupil; in the teacher tablet group, the technology component added US$3.00 per pupil. The e-readers added US$40 per pupil since the devices were provided to pupils at a 1:1 ratio. The total costs of the three PRIMR Kisumu interventions are shown in Fig. 2, which differentiates between the base cost of the PRIMR program and the additional ICT costs. The unit cost of the pupil e-reader intervention was

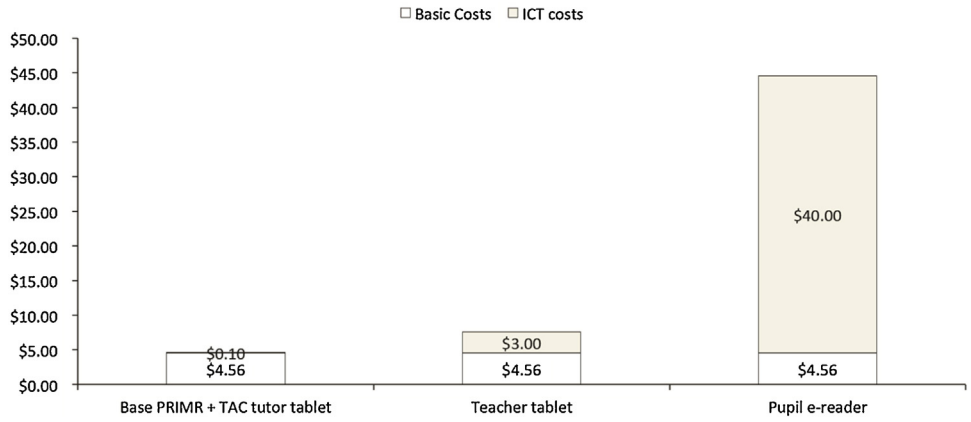

Fig. 2. Estimated per pupil costs of PRIMR ICT interventions.

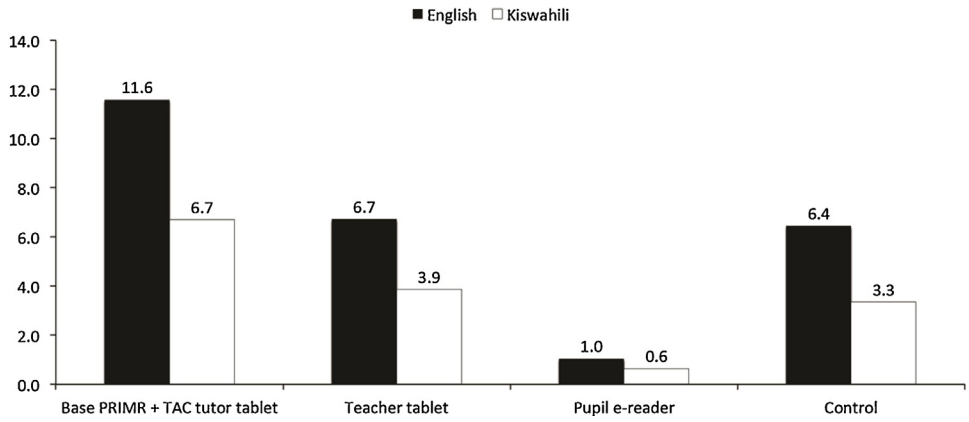

Fig. 3. ORF gains over baseline per pupil dollar spent.

significantly higher than those of the other treatments, even using the lower current estimated cost of basic e-readers.

Cost effectiveness for the treatment groups was measured by dividing the effect for each treatment by the respective per-pupil per-subject unit cost, computing the gains in ORF over baseline per dollar. Control group costs were calculated using the estimates identified in Piper et al. (2014). Fig. 3 shows that the base PRIMR TAC tutor tablet treatment group had the highest impact on oral reading fluency per dollar spent. For the base PRIMR TAC tutor tablet intervention, an investment of one dollar translated to an additional fluency of 11.6 cwpm for English and 6.7 cwpm for Kiswahili. The teacher tablet group was similar in cost effectiveness to the control group. Cost effectiveness was the lowest for the e-reader group, with the control group as well as the two other interventions showing much larger ORF gains per dollar than the e-reader group. Stated another way, it was much more cost-effective to implement the existing control condition than the pupil e-reader intervention. This will likely remain the case even as e-reader hardware costs drop, as our estimates used a reduced e-reader cost.

5.3. RQ3: How did the treatment effects compare to the base PRIMR program implemented elsewhere in Kenya?

To address this research question, we compared the EGRA results of the Kisumu PRIMR intervention groups with findings from three different versions of the PRIMR project. The first was the (non-ICT) PRIMR results collected at the end of 2012 after slightly less than one year of intervention in peri-urban locations (Piper et al., 2014). The second was the (non-ICT) PRIMR results collected after 2 years of intervention in the same peri-urban locations (Piper, Jepkemei et al., 2015), and the third was the (non-ICT) PRIMR results collected after 2 years of intervention in rural locations (Piper, Kwayumba et al., 2015). Fig. 4 presents the effects on ORF in English and Kiswahili for the three treatment groups of the ICT PRIMR program compared with the effects on ORF in the same subjects from the other three studies.

While the fact that the studies took place in different geographic locations at different times prevents causal inference from these comparisons, it provides evidence as to the potential value-added of technology as compared to the non-ICT version of the same program. Our analysis showed that the impacts of the three treatment groups in Kisumu were within the range of the base PRIMR program effects in the other three evaluations. The largest effects were identified after the first year of the base PRIMR initiative. The smallest effect for English was in the student e-reader program, and for Kiswahili the smallest was the 2-year effect of the base non-ICT PRIMR program. In other words, there does not appear to have been a systematic advantage to any of the ICT interventions over the non-ICT PRIMR programs, either in Kisumu County or elsewhere in Kenya. Some of the comparisons actually suggest a statistically significant advantage for the base PRIMR TAC tutor tablet program over the e-reader and teacher tablet programs. This suggests that there may be limited value-added to an ICT intervention, and that it may in fact distract somewhat from the implementation of the base program.

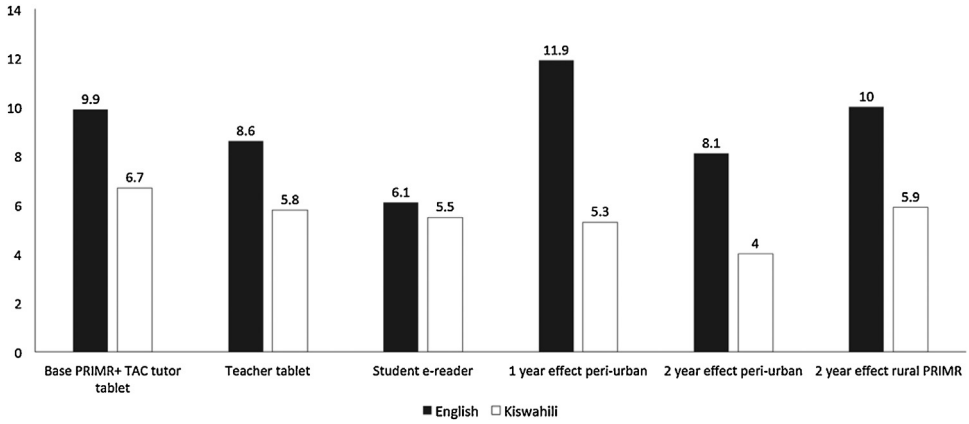

Fig. 4. Causal effects of ICT and base PRIMR program on oral reading fluency.

6. Discussion

This study aimed to determine whether ICT interventions can produce literacy learning gains for students in the early grades of primary school. Previous ICT literacy programs either have been poorly evaluated or have failed to produce impacts on learning outcomes. With the PRIMR ICT programs, we found that interventions using technology can be effective if they are used on top of a well-designed literacy program. However, our results also suggest that there may be limited value-added to the ICT component; the impact of the low-technology base version of PRIMR was similar to that of all three of the ICT groups, in terms of improvements in students' oral reading fluency in English and Kiswahili or gains in the proportion of pupils reading at the benchmark level. Given the costs of the ICT add-ons in this case, particularly the e-reader, the cost-effectiveness of such programs can be much lower than for the base program.

Despite the findings showing that student e-readers did not produce learning gains superior to the cheaper ICT options, e-readers are promising for many other reasons. Small studies in the United States and Canada have found that children enjoy reading on e-readers (Ciampa, 2012; Jones and Brown, 2011). They allow students access to many different books, both textbooks and pleasure reading books, at a low cost. In the Ghana study discussed above, students had on average 107 books on their e-readers, including 86 that were automatically loaded onto the e-reader and 21 the students had selected themselves (ILC Africa and Worldreader, 2012). In parts of rural Kenya where book distribution is a logistical challenge, this approach has the potential to dramatically reduce distribution costs. In the Kisumu ICT study, the researchers also found that students in the e-reader treatment group read 18 books over the course of the 2013 academic year and 70% consistently participated in regular free reading sessions in the afternoons (Piper and Kwayumba, 2014). However, these apparent successes in access to reading materials did not translate into significantly improved student performance over less intensive or costly ICT interventions. This may be in part because students' initial literacy skills were so poor that they did not get much benefit from unscaffolded reading time. It is possible that e-readers may be better suited to older children who are more capable of independent reading. This aligns with findings from the study cited above showing that children with stronger skills at the beginning of the program gained more (Kam et al., 2009), and with others indicating that mobile phone e-reading is most popular with people who are more educated than average in their countries (West and Chew, 2014). It is possible that a more structured program using the e-readers, giving the students specific activities and support, would improve results (Wijekumar et al., 2012).

A version of the e-reader program evaluated here was piloted in Ghana (ILC Africa and Worldreader, 2012) prior to the Kisumu County experiment, but the relatively complex TAC tutor tablet and teacher tablet interventions were not piloted before this evaluation. The technical tools developed for the TAC tutor tablet and teacher tablet interventions were created for the first time specifically for the Kisumu study. Larger outcomes might have been identified if all the ICT interventions had received a thorough pilot trial before the evaluation period began. The TAC tutor tablet program was utilized at a larger scale in the base PRIMR program starting in 2014 (Piper, Kwayumba et al., 2015). Results from that study, with a randomized controlled trial research design, showed large effects on learning outcomes. With a year of piloting, any of the tablet-based interventions might have shown larger effects during the subsequent evaluation phase.

The technology-intensive features of the teacher tablet program may have been a distraction for students and teachers. In this study, extensive training was required to enable teachers simply to learn to turn the tablets on and off, and to log in. One technical advisor spent 90 min helping a teacher in the teacher tablet group to consistently remember her username and password. While this teacher dramatically improved her ability to utilize the technology over the 8 months of the Kisumu ICT intervention, there was an opportunity cost: The time and energy spent to learn the technology could have been spent on instructional improvement activities. Finally, the teacher tablet program was the initial trial of the Tangerine:Class software, which gave teachers a significant amount of feedback on their students' performance. Anecdotal evidence showed that teachers who did use the findings found them useful. However, as noted, there might be an opportunity cost in terms of instructional quality when such technology requires significant effort.

A lack of technological exposure, including unfamiliarity with the capabilities of these types of devices, might also have limited the value added by the TAC tutor tablet program. For example, the TAC tutors did not appear to use the more advanced assessment and data collection features of the tablet frequently. One of the two TAC tutors in the TAC tutor tablet group struggled to utilize the applications on the tablets for the duration of the program, although the effect of the program in his zone remained large. This challenge might have been specific to that TAC tutor, as the tablet program was scaled up in 2014 to the base PRIMR program and the PRIMR technical team was able to confirm that TAC tutors used the tools consistently (Piper, Kwayumba et al., 2015). Anecdotal evidence from the scale-up of the TAC tutor tablet program as an addition to the base PRIMR program in Kenya suggests the potential of technology targeted at instructional improvement to ease the load of instructional supervisors and therefore provide a cost-effective contribution of ICT to improving learning outcomes (Piper, Kwayumba et al., 2015). The MoEST decided to scale up the TAC tutor tablet program beyond the 1384 PRIMR schools, and during 2015, each TAC tutor in Kenya was provided a tablet and training to implement the tablet-based instructional support system. This was done to support the Tusome national literacy program, implemented in each public primary school and 1000 low-cost private schools from 2015 to 2018.

The PRIMR endline evaluation included a questionnaire administered to the TAC tutors in the study. The TAC tutors were asked how many times they visited schools and classrooms in the past month. The control TAC tutors reported 9.2 visits to schools and 9.2 visits to classrooms. This contrasted with the responses of the PRIMR treatment TAC tutors, who reported 24.6 visits to schools and 41.0 classroom visits in the past month. These are self-reported statistics, and the PRIMR treatment TAC tutors would have been aware of the social desirability of reporting that they visited schools and classrooms in PRIMR. However, it did appear that the three PRIMR treatments had a significant impact on classroom support time. A simple OLS regression model revealed that every additional reported classroom visit was associated with a mean difference of 1.0 cwpm in English oral reading fluency, even controlling for assignment to treatment group. It appears that this increased attention to schools and classrooms was an important moderator for the PRIMR ICT and base PRIMR effect on learning outcomes.

The field of ICT in education is expanding its focus on measuring the impact of the ICT interventions on learning outcomes. This paper should provide evidence for policy makers as they consider further ICT investments of various types. If any of the three programs analyzed here had been evaluated against a control group alone, the results would have indicated an impressive effect on learning outcomes that might have made them eligible for scale-up or increased funding. For example, a simpler study that measured only the effect of the e-reader treatment group would have had convincing results of the impact of the e-reader program, larger than in previous e-reader evaluations (ILC Africa and

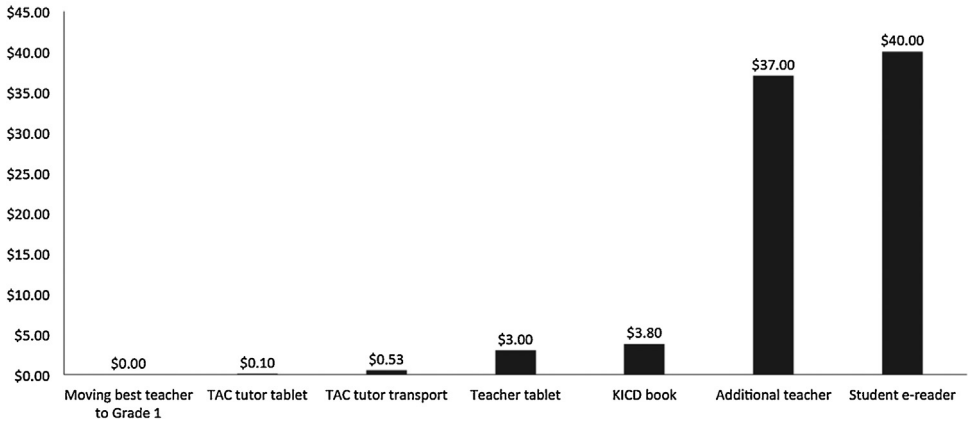

Fig. 5. Per pupil costs of policy options in the education sector.

Worldreader, 2012; Wagner, 2014). Countries have taken multi-million-dollar programs to scale with less evidence. The specific contribution of this paper is to examine not only whether particular ICT options were effective, but whether they were more effective than other options that were less expensive. This is an essential question for this subfield of education, and one that requires additional research beyond the modest contributions of this paper. More importantly, given the failure of earlier ICT-in-education studies to link the ICT investments to instructional improvement processes, this paper presents the results of the additional impact of ICT *on top of* an already effective instructional improvement program. Estimating not only whether the program worked, but whether it would work better than a less ICT-intensive alternative, is an important comparison in the policy and funding environments of many sub-Saharan African countries.

The Kenyan education sector is relatively well established, and provides an annual per-child capitation grant of US$14 to schools every year. Each school's Board of Management spends this money as it sees fit to improve education quality. The capitation grant is often late and sometimes insufficient, but it gives individual schools some flexibility in how they allocate funding. Fig. 5 provides some context for the ICT expenditures that schools could consider in such an environment. A simple and enormously effective change would be to assign the best teachers to Grade 1, rather than to the end of primary school as many schools do. This would have no cost, but significant effect. The TAC tutor tablet cost per pupil for the PRIMR studies was modest, at US$0.10 per child per year. Providing the TAC tutor with sufficient transport to visit every teacher every month cost US$0.53. The purchase and transport costs of a PRIMR (printed) book were somewhat higher, at US$0.75. An amount of US$3.00 per pupil was sufficient to provide a teacher a tablet, assuming the full cost was allocated in one year, as was done in this study; spreading the cost over two years would reduce the annual cost to US$1.50. Student textbooks approved by the Kenya Institute of Curriculum Development (KICD) and already in the market cost more than this, at somewhat less than US$4 per book. As another comparison, paying the salary (but not allowances) of an additional teacher would cost US$37 per student per year, which is slightly less expensive than providing an e-reader to each child. This figure shows that some ICT costs can be minimal (the TAC tutor tablet, for example) while others are extremely expensive relative to schools' other spending options. This is highly relevant to the Kenyan government's debate on whether to move forward with the election promise to provide laptops to each Grade 1 child, which will cost at least US$200 per pupil, as currently conceived. This analysis shows clearly that it is essential to examine actual costs and opportunity costs and use them in decisions related to the provision of ICT in education.

7. Limitations

The findings for research questions 1 and 2 are drawn from differences-in-differences results, allowing an estimate that attempts to show the causal effect of the three treatment groups. To answer research question 3, we compared the impacts of PRIMR in Kisumu County to those in other counties in Kenya, including the base PRIMR program providing tablets for TAC tutors. We cannot infer causality in the comparison of the PRIMR studies outside of Kisumu County and the treatment groups in Kisumu County. However, as the Kenya PRIMR studies have expanded geographically and over time, the results have been relatively consistent: improvements of 4–12 cwpm per academic year on assessments of ORF and program effects of 0.2–0.5 standard deviations on a range of learning outcomes (Piper, Jepkemei et al., 2015; Piper, Kwayumba et al., 2015; Piper et al., 2014). These effects are remarkably similar to what was identified in the one-year ICT study in Kisumu County, and make it more likely that the noncausal comparison is reasonable.

Few of the comparisons between the Kisumu treatment groups showed statistically significant differences. This is in part because the impacts on learning outcomes were similar, but also because the study was underpowered to undertake pairwise comparisons and identify statistically significant differences with small effects. Additional research in this area of comparison between treatment groups will require a larger sample to have enough statistical power to estimate the relative impact of the interventions.

8. Conclusion

The Kisumu ICT study allowed for a comparative analysis of the impact of ICT on learning outcomes in Kenya when interventions took place at three different levels in the education system: student, teacher, and instructional coach. The results of all three of the Kisumu County interventions showed that literacy outcomes can be improved. Despite great excitement over ICT interventions to support literacy, however, technology is not a cure-all for the poor literacy outcomes in Kenya and other countries in sub-Saharan Africa. In this case, whereas technology may have helped TAC tutors to better provide instructional support, we found no evidence that providing tablets to teachers or e-readers to students was more effective than the base PRIMR literacy program that was implemented without expensive ICT. When costs are

considered, there are non-ICT interventions that could have larger impacts on learning outcomes with lower cost. Our analysis suggests that, for future interventions, tablets and e-readers should primarily be a conduit supporting improved instructional interventions. As the body of knowledge created by this and other studies continues to grow, we recommend that future research focus on the nuances of ICT for classroom literacy interventions (Wagner, 2014)—that is, what works best, in the most cost-effective designs, for whom, and in which contexts.

Funding source

Implementation of the Primary Math and Reading (PRIMR) Initiative in Kenya (2011–2014) was led by RTI International. The program was funded by the United States Agency for International Development (USAID/Kenya), under the Education Data for Decision Making (EdData II) Blanket Purchase Agreement, Task Order 13, Contract No. AID-623-M-11-00001. USAID/Kenya participated in PRIMR design and implementation decisions, and also granted the authors permission to use the data set for additional analysis and dissemination. The lead author, Dr. Benjamin Piper, served as USAID's Chief of Party on the PRIMR Initiative. Costs for preparing the article were covered jointly by PRIMR and by an internal Professional Development Award issued by RTI International. The contents of the article and decisions about publication were the sole responsibility of the authors. The authors' views expressed in this publication do not necessarily reflect the views of USAID, the United States Government, or RTI International.

References

Ciampa, K., 2012. Reading in the digital age: using electronic books as a teaching tool for beginning readers. Can. J. Learn. Technol. 38 (2) . http://www.editlib.org/p/42890/.

Cristia, J.P., Ibarrarán, P., Cueto, S., Santiago, A., Severín, E., 2012. Technology and child development: evidence from the one laptop per child program. IDB Working Paper Series No. IDB-WP-304. Inter-American Development Bank, Washington, DC. https://www.aeaweb.org/aea/2013conference/program/meetingpapers.php.

Dubeck, M.M., Gove, A., 2015. The early grade reading assessment (EGRA): its theoretical foundation, purpose, and limitations. Int. J. Educ. Dev. 40, 315–322. http://dx.doi.org/10.1016/j.ijedudev.2014.11.004.

Gove, A., Cvelich, P., 2011. Early Reading: Igniting Education for All. A Report by The Early Grade Learning Community of Practice (Rev. Ed.). RTI International, Research Triangle Park, NC. http://dx.doi.org/10.3768/rtipress.2011.bk.0007.1109.

The Early Grade Reading Assessment: Applications and Interventions to Improve Basic Literacy. In: Gove, A., Wetterberg, A. (Eds.), RTI Press, Research Triangle Park, NC. http://www.rti.org/pubs/bk-0007-1109-wetterberg.pdf.

Grace, J., Kenny, C., 2003. A short review of information and communication technologies and basic education in LDCs—what is useful, what is sustainable? Int. J. Educ. Dev. 23 (6), 627–636. http://dx.doi.org/10.1016/S0738-0593(03)00062-2.

Hanushek, E.A., Woessmann, L., 2012. Do better schools lead to more growth? Cognitive skills, economic outcomes, and causation. J. Econ. Growth 17 (4), 267–321. http://dx.doi.org/10.1007/s10887-012-9081-x.

ILC Africa and Worldreader, 2012. iREAD [Impact on Reading of E-Readers and Digital content] Ghana Study: Final Evaluation Report. USAID, Washington, DC. http://pdf.usaid.gov/pdf_docs/pnadz402.pdf.

Jere-Folotiya, J., Chansa-Kabali, T., Munachaka, J., Sampa, F., Yalukanda, C., Westerholm, J., Lyytinen, H., 2014. The effect of using a mobile literacy game to improve literacy levels of grade one students in Zambian schools. Educ. Technol. Res. Dev. 62 (4), 417–436. http:/dx.doi.org/0.1007/s11423-014-9342-9.

Jones, T., Brown, C., 2011. Reading engagement: a comparison between e-books and traditional print books in an elementary classroom. Int. J. Instr. 4 (2), 5–22. http://www.e-iji.net/dosyalar/iji_2011_2_1.pdf.

Kam, M., Kumar, A., Jain, S., Mathur, A., Canny, J., 2009. Improving literacy in rural India: cellphone games in an after-school program. Paper presented at the Third International Conference on Information and Communication Technologies and Development .

Kim, P., Buckner, E., Kim, H., Makany, T., Taleja, N., Parikh, V., 2012. A comparative analysis of a game-based mobile learning model in low-socioeconomic communities of India. Int. J. Educ. Dev. 32 (2), 329–340. http://dx.doi.org/10.1016/j.ijedudev.2011.05.008.

Marteleto, L., Lam, D., Ranchhod, V., 2008. Sexual behavior, pregnancy, and schooling among young people in urban South Africa. Stud. Fam. Plann. 39 (4), 351–368. http://dx.doi.org/10.1111/j.1728-4465.2008.00180.x.

McEwan, P.J., 2014. Improving learning in primary schools of developing countries: a meta-analysis of randomized experiments. Rev. Educ. Res..

Mugo, J., Kaburu, A., Limboro, C., Kimutai, A., 2011. Are Our Children Learning? Annual Learning Assessment Report. Uwezo, Nairobi. http://www.uwezo.net/wp-content/uploads/2012/08/KE_2011_AnnualAssessmentReport.pdf.

Murnane, R.J., Willett, J.B., 2011. Methods Matter: Improving Causal Inference in Educational and Social Science Research. Oxford University Press, New York.

Onsomu, E., Nzomo, J., Obiero, C., 2005. The SACMEQ II Project in Kenya: A Study of the Conditions of Schooling and the Quality of Education. Southern and Eastern Africa Consortium for Monitoring Educational Quality (SACMEQ) and Kenya Ministry of Education, Science and Technology, Harare and Nairobi.

Piper, B., Miksic, E., 2011. Mother tongue and reading: using early grade reading assessment to investigate language-of-instruction policy in East Africa. In: Gove, A., Wetterberg, A. (Eds.), The Early Grade Reading Assessment: Applications and Interventions to Improve Basic Literacy. RTI Press, Research Triangle Park, NC, pp. 139–182. http://dx.doi.org/10.3768/rtipress.2011.bk.0007.1109.

Piper, B., Mugenda, A., 2012. The Primary Math and Reading (PRIMR) Initiative: Baseline Report. Prepared Under the USAID Education Data for Decision Making (EdData II) Project, Task Order No. AID-623-M-11-00001 (RTI Task 13). RTI International, Research Triangle Park, NC. http://pdf.usaid.gov/pdf_docs/pa00hx75.pdf.

Piper, B., Kwayumba, D., 2014. The Primary Math and Reading (PRIMR) Initiative. Kisumu Information and Communication Technology (ICT) Intervention: Endline Report. Prepared Under the USAID Education Data for Decision Making (EdData II) Project, Task Order No. AID-623-M-11-00001 (RTI Task 13). RTI International, Research Triangle Park, NC. http://pdf.usaid.gov/pdf_docs/pa00k285.pdf.

Piper, B., Zuilkowski, S.S., Mugenda, A., 2014. Improving reading outcomes in Kenya: first-year effects of the PRIMR initiative. Int. J. Educ. Dev. 37, 11–21. http://dx.doi.org/10.1016/j.ijedudev.2014.02.006.

Piper, B., Zuilkowski, S.S., 2015. Teacher coaching in Kenya: examining instructional support in public and nonformal schools. Teach. Teach. Educ. 47, 173–183.

Piper, B., Jepkemei, E., Kibukho, K., 2015a. Pro-poor PRIMR: improving early literacy skills for children from low-income families in Kenya. Afr. Educ. Rev. 12 (1) . http://dx.doi.org/10.1080/18146627.2015.1036566.

Piper, B., Kwayumba, D., Oyanga, A., 2015b. The Primary Math and Reading (PRIMR) Initiative DFID/Kenya Rural Expansion Programme, Bungoma and Machakos Endline Study. Prepared for DFID/Kenya Under Contract 202657-108. RTI International, Research Triangle Park, NC. https://www.eddataglobal.org/countries/index.cfm?fuseaction=pubDetail&ID=806.

RTI International, 2013. Mobile Technology for Learning Assessments. http://www.tangerinecentral.org/aboutsite (Web page).

Roschelle, J., 2003. Keynote paper: unlocking the learning value of wireless mobile devices. J. Comput. Assisted Learn. 19 (3), 260–272. http://dx.doi.org/10.1046/j.0266-4909.2003.00028.x.

Strigel, C., Lang'o, M., Kwayumba, D., Koko, S., 2015. Case study: tangerine: class for data-informed instructional decision making in Kenya. In: Crompton, H., Traxler, J. (Eds.), Mobile Learning And Mathematics: Foundations, Design, and Case Studies. Routledge, New York, pp. 198–212.

Trucano, M., 2005. Knowledge Maps: ICTs in Education. infoDev/World Bank, Washington, DC. http://www.infodev.org/infodev-files/resource/InfodevDocuments_8.pdf.

United Nations Educational, Scientific and Cultural Organization (UNESCO), 2014. Teaching and Learning: Achieving Quality for All. Education for All Global Monitoring Report. UNESCO, Paris. http://www.unesco.org/new/en/education/themes/leading-the-international-agenda/efareport/reports/2013/.

Wagner, D., Day, B., James, T., Kozma, R.B., Miller, J., Unwin, T., 2005. Monitoring and Evaluation of ICT in Education Projects: A Handbook for Developing Countries. infoDev/World Bank, Washington, DC. http://www.infodev.org/articles/monitoring-and-evaluation-ict-education-projects.

Wagner, D., 2014. Mobiles for Reading: A Landscape Research Review. USAID, Washington, DC. http://pdf.usaid.gov/pdf_docs/pa00jtgt.pdf.

Wasanga, P.M., Ogle, A.M., Wambua, R.M., 2010. Report on Monitoring of Learner Achievement for Class 3 in Literacy and Numeracy. Kenya National Examinations Council, Nairobi. http://www.knec.ac.ke/main/index.php?option=com_phocadownload&view=category&download=182:std-3-abridged-report&id=62:std-3-abridged-report.

West, M., Chew, H.E., 2014. Reading in the Mobile Era: A Study of Mobile Reading in Developing Countries. UNESCO, Paris. http://unesdoc.unesco.org/images/0022/002274/227436e.pdf.

Wijekumar, K.K., Meyer, B.J.F., Lei, P., 2012. Large-scale randomized controlled trial with 4th graders using intelligent tutoring of the structure strategy to improve nonfiction reading comprehension. Educ. Technol. Res. Dev. 60 (6), 987–1013. http://dx.doi.org/10.1007/s11423-012-9263-4.

Winters, P., Davis, B., Carletto, G., Covarrubias, K., Quiñones, E.J., Zezza, A., Azzarri, C., Stamoulis, K., 2009. Assets, activities and rural income generation: evidence from a multicountry analysis. World Dev. 37 (9), 1435–1452. http://dx.doi.org/10.1016/j.worlddev.2009.01.010.

Worldreader, 2013. Improving E-Reader Durability. Worldreader, San Francisco, CA. http://cdn.worldreader.org/wp-content/uploads/2013/11/Improving-E-reader-Durability.pdf.