Research Article

Improving Child Literacy in Africa: Experiments with an Automated Reading Tutor*

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Abstract

This paper describes Project Kané, a research endeavor aimed at exploring the role that technology can play in improving child literacy in developing communities. An initial pilot study and a subsequent four-month-long controlled field study in Ghana investigated the viability and effectiveness of an automated reading tutor in helping urban children enhance their reading skills in English. In addition to quantitative data suggesting that automated tutoring can be useful for some children in this setting, these studies and an additional preliminary pilot study in Zambia yielded useful qualitative observations regarding the feasibility of applying technology solutions to the challenge of enhancing child literacy in developing communities. This paper presents the findings, observations, and lessons learned from the field studies.

1. Introduction

Literacy is a key part of the global development agenda. The United Nations recognizes literacy as a human right, noting that basic education, of which literacy is the key learning tool, was recognized as a human right more than 50 years ago in the Universal Declaration of Human Rights.

As a contribution to the discourse on applying information and communication technologies (ICTs) to address development challenges, we describe a study exploring the potential role of computing technology, specifically an automated reading tutor, in improving English literacy among Ghanaian and Zambian children who attend school in English but have low reading achievement levels.

Low functional literacy among individuals who have completed primary school is not an uncommon problem in developing communities. For example, UNESCO (2005) reports that, in 2000, more than one in three adults with a fifth-grade education in Chad and Niger reported that they could not read. In other cases, individuals may finish primary school reading below the expected level. In a representative sample of Ghanaian public schools, reading achievement levels measured by the government-administered Criterion Referenced Test in 2000 indicated that fewer than 10% of the children in grade six were able to read with grade level mastery (Lipson & Wixson, 2004).

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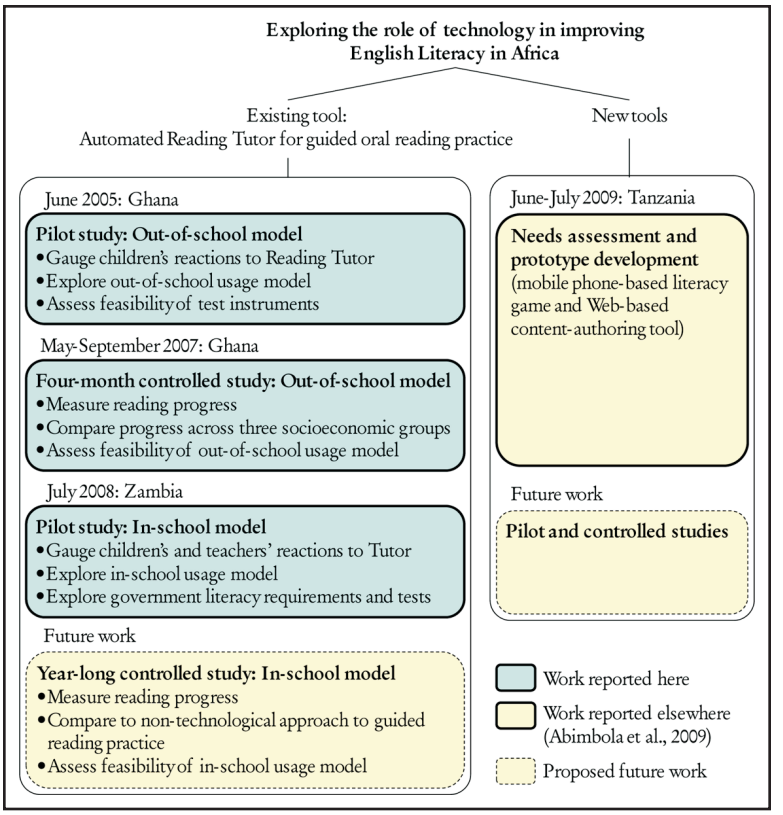

Figure 1. Project outline.

Several factors contribute to this problem. For the average child from a rural or low-income urban background in Africa, reading is not part of daily family life, and sometimes, parents are not themselves literate. In Ghana and Zambia specifically, most children speak one of a number of local languages at home, but they attend school classes taught in English, the official language for both countries. Typically, under-resourced schools with overcrowded classrooms offer few opportunities for individual attention while students are developing reading skills, and many areas have the additional challenge of inadequately trained teachers (Clegg, Ogange, & Rodseth, 2003).

Project Kané, described in this paper, is a proof-of-concept study designed to investigate whether an automated computer-based reading tutor that provides guided reading practice can significantly improve the reading proficiency of children in a developing community, even if they have no prior familiarity with computers. We focus our study on children in Accra, Ghana, and Mongu, Zambia. As illustrated in Figure 1, this work is part of a larger research endeavor exploring the role of technology in improving English literacy in Africa.

We began by employing the Reading Tutor in a preliminary three-week-long pilot study in Accra, Ghana. The pilot study was used to explore technical and operational feasibility, and to motivate partnerships and funding for a longer term study. We followed up with a four-month-

long controlled study in Accra, in collaboration with the Ghana-India Kofi Annan Centre for Excellence in ICT (AITI-KACE) and with input from Associates for Change, an educational research firm in Accra. The controlled study aimed at quantitatively measuring the educational effectiveness of the tutor when it was employed with an out-of-school usage model by children in Accra. Observations and lessons from these experiences fed into another pilot study in Mongu, Zambia, this time employing an in-school usage model, with the plan of following up with an additional controlled study in the future.

The main contributions of this work are a quantitative analysis of the effectiveness of the Reading Tutor, as well as a discussion of the lessons learned, concerning both study implementation and the viability of automated tutoring for this context.

Section 2 describes the skills that are involved in reading and introduces the automated tutor we used in this project. Section 3 discusses prior work on the use of technology to support literacy in developing communities. Section 4 outlines the overarching study objectives. Sections 5, 6, and 7 describe the pilot field study in Ghana, the four-month-long controlled study in Ghana, and the pilot study in Zambia, respectively. Section 8 distills practical lessons learned in the implementation of these field studies, and Section 9 concludes with a discussion of future work.

2. Background

As a cognitive proficiency, reading involves several component skills, such as phonemic awareness, decoding, fluency, vocabulary, and comprehension (National Institute of Child Health and Human Development [NICHD], 2000). Phonemic awareness is the ability to perceive individual sounds or *phonemes* in words. Building on this awareness, a child learns the alphabetic principle that spelling generally maps systematically to pronunciation. The child also learns specific letter-sound correspondences and the ability to correctly pronounce written words (decoding). Fluency is the ability to read text accurately, quickly, and expressively, and it is an important foundation for comprehension. A rich vocabulary is essential for comprehension and effective communication. Children develop these skills through a variety of experiences, including skilled instruction. Research has shown that regular guided oral reading plays an important role in developing reading skills, particularly fluency and comprehension (NICHD, 2000).

Such guided oral reading may happen in small groups in a classroom setting, or with parents at home. Technology may also assist in this process: Scientific Learning's *Reading Assistant,* evaluated in Adams (2006), and Project LISTEN's *Reading Tutor* (Mostow & Aist, 2001) are examples of computer-based tools that use automated speech recognition to provide a guided reading experience for the user.

The project described in this paper used Project LISTEN's Reading Tutor, which has demonstrated success in improving the reading abilities of children, both those whose first language is English (Mostow & Aist, 2001; Mostow et al., 2008) and those learning English as a second language (ESL) in the United States (Poulsen, Hastings, & Albritton, 2007) and Canada (Reeder, Shapiro, Early, Kendrick, & Wakefield, 2005).

The Reading Tutor displays stories on a screen and "listens" to a child read aloud. By using speech recognition to analyze the child's reading, the Reading Tutor is able to give graphical and spoken feedback. It gives help when it detects a long pause, a severely misread word, or a skipped word, and also when the reader clicks for help. The tutor may speak the whole word out loud or decompose the word into syllables or phonemes and speak out each part while highlighting it. It may also give a "rhymes with" hint, or read the sentence by playing a fluent human narration to model expressive reading. The Reading Tutor includes a wide variety of stories at different reading levels. It takes turns with the child in selecting a story to read. It monitors the child's reading progress and selects stories at an appropriate level for the child. The Reading Tutor also provides activities to let children author new content themselves. For readers at early stages of development, the Reading Tutor includes word-building exercises to develop knowledge of spelling-to-sound correspondences. Videos of the Reading Tutor in use may be found at Project LISTEN's website (www.cs.cmu.edu/~listen).

3. Relation to Prior Work

There is a great deal of discussion, such as that by Wagner, Day, and Sun (2004), about the potential for ICTs to make an impact on education in the

developing world. There is now a recognized need for a greater focus on rigorous evaluations of the impact of technology on educational outcomes in developing communities as a first step in enabling policy makers to make effective decisions (Wagner, 2005). There is some evidence, so far, of a positive impact on student learning from ICT tools targeted at specific subject areas (Kozma, 2005). For example, projects in India (Banerjee, Cole, Duflo, & Linden, 2007) and South Africa (Louw, Muller, & Tredoux, 2008) have shown improvements in mathematics performance as a result of using math-related software. Evaluations such as these, still quite rare, show the potential impact of ICTs on education in developing communities.

In the domain of literacy and language learning, one of the most significant projects related to our work is the MILLEE project (Kam et al., 2008), which develops mobile phone games to assist with English as a Second Language (ESL) learning. User-centered design and evaluation of these games have been focused on rural communities in India. The most recent quantitative evaluation of this tool showed a significant positive impact on ESL learning by children in an after-school program (Kam, Kumar, Jain, Mathur & Canny, 2009).

The work reported in the current paper contributes to the discourse by studying a different part of the research space than has been previously studied: the use of technology to support English literacy among urban children in English-speaking Africa. It is important to evaluate the effectiveness of different kinds of tools, as the capabilities of different platforms vary greatly. Mobile phones are much more pervasive in the developing world than personal computers. However, for reading and writing instruction, the personal computer has some key advantages over the mobile phone: It has an easier input device and a large screen that can display full paragraphs of connected text. In the work reported in this paper, we take advantage of the fact that computers are more pervasive and viable in urban areas than they are in rural areas. We evaluate the use of a computer-based automated reading tutor in this context, exploring both in-school and out-of-school usage scenarios.

4. Study Objectives

The primary objective of our studies was to evaluate the feasibility and effectiveness of the automated reading tutor in the setting of interest. Two secondary objectives were to explore practical usage scenarios for the tutor, and to learn lessons related to conducting such studies in this environment. As such, we comment on all three aspects in this paper.

In Ghana, we focused on an out-of-school usage model for the practical reason that most of the schools with which we worked did not have computer labs. This is typical of most under-resourced public schools in this setting, and therefore, it was important to explore what would be possible without significant additional infrastructure investment in the schools. In Zambia, we focused on an in-school usage model, since the schools we worked with had computers donated by a non-governmental organization.

5. Ghana: Pilot Study

A. Goal

The 2005 Ghana pilot study aimed to evaluate the practicality of a technological approach to guided reading practice in Accra, and to investigate the feasibility of conducting a longer-term controlled study.

Specifically, we wished to answer the following questions:

1. *Partners and logistics:* How feasible is it to engage partners and arrange the logistics for such a study?
2. *Learning to use the Reading Tutor:* How quickly do children with no prior computer experience learn to operate the Reading Tutor, and what instruction do they need in order to do so?
3. *Speech:* Does the speech recognition software perform acceptably with Ghanaian accents, and can the students understand the narrated speech?
4. *Tutor content:* Do the children find the reading material in the tutor engaging?
5. *Usage sessions:* What is an effective length for a tutoring session?
6. *Reading measures:* Which test instruments can be used easily and effectively to assess reading proficiency in the Ghanaian setting?

B. Participants and Methodology

We chose to focus on the needs of children from low-income families attending public school because they have a high risk of low achievement in reading.

In consultation with Associates for Change, we targeted children in grades two through four, since this is a key period for developing reading skills after the initial adjustment to the primary school environment. We restricted our work to an urban environment where computers are more readily available in the community, but where significant literacy challenges still exist. As the school did not have its own computer lab, we employed an out-of-school usage model in which practice with the Reading Tutor was supplemental to regular school activities.

The pilot study involved qualitative observations of children as they used the Reading Tutor. The study was conducted by the first author, who is a native of Ghana, assisted by a local volunteer. Two groups of children participated in this study. One group comprised 12 children in grades two through four from an under-resourced public school. They used the Reading Tutor at an Internet café near their school for 20–30 minutes each day over a three-week period. The other group comprised six children from a mixed low- and middle-income neighborhood. They used the tutor on laptops in the home of the researcher, for 20–30 minutes each day, three days a week, over the same period.

C. Results and Observations

The school and Internet café agreed without hesitation to participate in the project, and logistics were arranged very quickly. Teachers assisted by providing class lists from which the researchers selected participants at random, but because the study took place off-site at an Internet café, the teachers were not directly involved in the pilot study. The parents were happy to have their children participate in a project that could potentially be of benefit to them, and that did not have a fee for participation. The children were excited at the opportunity to use a computer and honored to be selected to participate. The Internet café donated time on four desktop computers at a time when the Reading Tutor could be used. We engaged the remaining children in other activities while they waited their turn. This worked for the pilot project, but it would not scale for a larger study.

Although one child had previously played a computer game, none of the other children had used a computer before. The children were given an initial 10–15 minute hands-on lesson introducing them to the computer and showing them how to use the mouse and keyboard. We then launched the Reading Tutor and had them go through the built-in automated tutorials on its operation. We found that the children had trouble understanding these automated tutorials due to the unfamiliar narration accent, so we explained the tutorials one-on-one to the children during their first two sessions, instead. We later re-narrated these tutorials in a Ghanaian accent. The children appeared to understand all other prompts given by the Reading Tutor. By their second or third session, most of the children were able to operate the Reading Tutor without help. Sometimes, the tutor would time-out if a child was idle for a while, and the project staff would need to show him or her how to log in again. On other occasions, a child would need to be encouraged to spend less time browsing the list of stories and more time reading. The project staff did not give any reading instruction or help to the children. The speech recognition capability appeared to work adequately with the children's accents. Also, based on the graphical feedback given by the tutor, the children quickly learned to recognize those occasions when it did not "hear" them correctly, and to repeat themselves when necessary. Although quantitatively analyzing the accuracy of the speech recognition was outside the scope of the project, we did not see any qualitative evidence of speech recognition problems serious enough to interfere with the performance of the Reading Tutor.

Overall, the children were very enthusiastic about using the Reading Tutor. Most of them appeared to enjoy the word-building exercises and the stories. However, we noticed that a couple of children, who were older than the norm (11 or 12 years old) but had a kindergarten or first grade reading level, were not as engaged by the content of the simple stories available for their reading level. Furthermore, we believe it would be good to incorporate more local content, such as Ghanaian folk tales, into the tutor. Unfortunately, time constraints limited our ability to do so. We noticed that the better readers could use the tutor for more than half an hour at a time without getting bored, whereas the more challenged readers would tire after about 20 minutes, but still looked forward to their next turn. We thus decided to limit the length of usage sessions in the controlled study to 20–30 minutes.

Although the pilot study did not aim to quantitatively measure reading progress, we chose an oral reading fluency test (Deno, 1985) and the Test of Written Spelling (TWS) (Larsen, Hammill, & Moats,

Figure 2. A child in Accra reading a story using the Reading Tutor.

1999) to assess reading ability, and we experimented with both of these test instruments during the pilot study, in preparation for the controlled study. These are both timed, hand-scored tests which we chose to use because they have been frequently used in previous studies measuring the effectiveness of the Reading Tutor, and they are psychometrically reliable, fast, and easy to administer. The fluency test is a reading exercise where the child is given a grade-appropriate story to read. It is scored as the number of words read correctly in one minute. The TWS is a dictation exercise where the child writes words read by the tester in order of increasing difficulty. It is scored as the number of words spelled correctly. The students did not have trouble with the format of either test. We modified the fluency test passages to use Ghanaian names and referred to the tests as "exercises" to prevent student anxiety about being tested.

6. Ghana: Controlled Study

A. Goal

Following on the success of the pilot study, the goal of the controlled study in Ghana was to quantitatively measure the efficacy of the Reading Tutor in helping children improve their reading skills. Specifically, we wished to determine:

1. Does regular use of the Reading Tutor improve oral reading fluency and spelling?
2. Do treatment effects depend on other factors, such as school/socioeconomic background, gender, or grade level?

Another goal of the controlled study was to learn about the operational feasibility of an out-of-school usage model, taking into consideration installation and maintenance of the software, training of staff responsible for the day-to-day running of the project, transportation of the children between the school and the project site, and other logistics. The controlled study was deployed by project staff at AITI-KACE, with remote training and support by our team in Pittsburgh.

B. Study Design/Methodology

The controlled study involved 89 children from three schools. The participating schools, recruited by Associates for Change, effectively catered to children from three different socio-economic backgrounds, respectively: S1, a private school in a middle-income community; S2, a public school in a low-income community; and S3, an informal educational program for highly disadvantaged children who have never attended formal school. The study involved children in grades two through four of S1 and S2, and in the "Intermediate" and "Advanced" levels (roughly corresponding to grades two and three, respectively) of S3.

The children were split randomly across school, grade, and gender boundaries into two groups, Tutor-1st and Control-1st, as shown in Table 1. We used a two-treatment crossover study design, illustrated in Table 2. For the first half of the study, the Tutor-1st group used the Reading Tutor while the Control-1st group had no additional reading intervention, and for the second half, the roles were switched: the Control-1st group used the Reading Tutor while the Tutor-1st group had no additional reading intervention. Each half of the study lasted nine weeks (two months), during which time there were daily usage sessions of approximately half an hour per child, although attendance and usage varied considerably. The statistical reason for a crossover design was to control for between-student variance by using each child as his/her own control, that is, by answering the question of whether a *particular* child gained more while using the Reading Tutor than while not using the Reading Tutor. Another advantage of a crossover design is that fewer participants are needed than would be needed for a parallel group trial with the same statistical power (Senn, 1993). The crossover design also had the advantage of equity, in that all participating children had the opportunity to use the

Table 1. Study participants by school, grade, and gender.

School	Grade	Number of Children			
		Tutor-1st		Control-1st	
		Female	Male	Female	Male
S1 (29 children)	Grade 2	3	2	2	3
	Grade 3	5	2	1	3
	Grade 4	1	3	3	1
S2 (30 children)	Grade 2	2	3	3	2
	Grade 3	3	2	1	4
	Grade 4	3	2	3	2
S3 (30 children)	Intermediate	3	4	3	5
	Advanced	3	5	5	2

Table 2. Cross-over study design.

	Tutor-1st Group	Control-1st Group
	Pre-testing of all children	
First half of cross-over (1st nine weeks)	Reading Tutor	Control: no special intervention
	Mid-way testing of all children	
Second half of cross-over (2nd nine weeks)	Control: no special intervention	Reading tutor
	Post-testing of all children	

Reading Tutor at some point. The major potential disadvantage of crossover designs is that carryover treatment effects from the first half may affect the second half. The standard structure of the two-treatment crossover, in which each half of the participants experiences a different treatment order, can help identify such an effect during analysis.

A battery of three fluency tests and one TWS were administered to all the children at the beginning of the study *(pre-testing),* between the two halves *(mid-way testing),* and at the end *(post-testing).* The testing was conducted at the children's schools by AITI-KACE project staff. Three fluency tests were used to better estimate reading ability. The passages used for these tests respectively correspond roughly to first, second, and third grade reading levels, since a test close to the child's current reading level should give a more sensitive measure of progress. We found that the scores on the three passages were highly correlated, so, for analysis purposes, these scores were combined into a single mean fluency score.

Of the participating schools, S1 had a computer lab, while S2 and S3 did not. To ensure similar study conditions for all participants, children from all three schools used the Reading Tutor in a computer lab at AITI-KACE. The computers used for the project had 2.4GHz Pentium IV processors, 256MB of RAM, and 16GB hard drives (shared with other projects). The suggested (not necessarily minimum) specifications for running the Reading Tutor are a 700 Mhz processor, 256 MB of RAM, a 40 GB hard drive, full duplex audio card, and Windows 2000 or Windows XP. Because of the smaller hard-disk space on the machines used, speech logs from the tutor had to be backed-up regularly.

C. Deviation from Study Design

In a normal crossover study, experimental conditions are held constant over the course of the study. However, due to logistical challenges that delayed the

Table 3. Modified study design.

	Tutor-1st Group	Control-1st Group
	Pre-testing of all children	
Experiment 1 (1st nine weeks)	School + Reading Tutor	Control: school only
	Mid-way testing of all children	
Experiment 2 (2nd nine weeks)	Control: No school	No school + Reading tutor
	Post-testing of all children	

start of the project, the first half of this study took place while the students were attending school, whereas the second half overlapped with the school vacation. Because of the different conditions in place during the two halves of the study, we analyzed the results as two different experiments, rather than as a single crossover study. The first experiment measured the effect of the Reading Tutor while the children attended school (and thus attended English class as usual). The second experiment measured the effect of the tutor while the children did not attend school (and so did not attend English class). This modified study design is illustrated in Table 3.

D. Results and Analysis

Figure 3 illustrates the pre-test scores of children at the three schools, representing their reading proficiency going into the study. It is clear that the S1 children had much higher levels of reading achievement than the S2 children, who, in turn, had higher levels than the S3 children. Pre-testing for our study occurred about two months before the end of the school year. To provide some context for these scores, Table 4 compares the fluency pre-test scores with end-of-year norms from schools in the United States (Hasbrouck & Tindal, 2006). By this standard, the average reading proficiency of the S1 students appears to be at or above the U.S. average, whereas those of the S2 and S3 children are lower. Norms from schools in Ghana are not available for comparison.

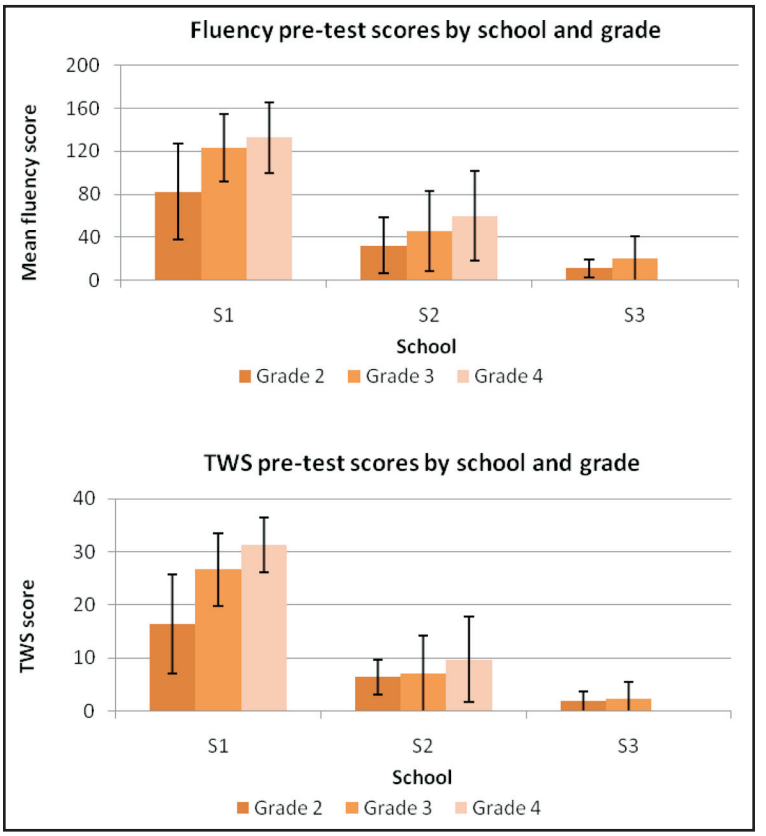

Figure 3. Pre-test scores by school and grade.

In analyzing each experiment, we focus on gains in fluency and spelling test scores. For experiment 1, the gain is the difference between pre- and mid-test scores; for experiment 2, the gain is the difference between the mid- and post-test scores. A positive gain

Table 4. Fluency pre-test scores compared with U.S. norms.

Grade / Level	Mean pre-test fluency (standard deviation)			Year-end U.S. Norm* (50th percentile)
	S1	S2	S3	
2 / "Intermediate"	82.4 (44.8)	32.3 (25.9)	11.1 (8.5)	89
3 / "Advanced"	123.3 (31.4)	45.8 (37.4)	20.4 (20.8)	107
4	132.7 (32.7)	59.8 (41.5)	—	123

** Data from Hasbrouck & Tindal (2006)*

Table 5. Comparison of treatment and control gains for experiment 1.

Test	School	Treatment (Tutor-1st group, N=41)	Control (Control-1st group, N=42)	*t*-test comparison of treatment & control gains	
		Mean Gain (SD)		p-value	Effect size
Fluency (# words read correctly per min)	S1	8.6 (20.5)	21.5 (11.7)	0.0833	−0.775
	S2	**61.4 (22.9)**	**23.4 (21.0)**	**<0.0001**	**1.731**
	S3	**13.4 (9.3)**	**5.1 (4.4)**	**0.0054**	**1.144**
TWS (# words spelled correctly)	S1	−1.9 (4.9)	−0.2 (2.6)	0.2997	−0.457
	S2	**3.9 (2.7)**	**0.3 (3.4)**	**0.0039**	**1.153**
	S3	2.8 (4.0)	0.6 (1.7)	0.0648	0.719

indicates improvement in the child's reading proficiency.

In each experiment, we use a standard statistical *t*-test to compare the mean gains of the treatment and the control group. This test yields a *p*-value indicating how significant the difference is between the means of the two groups. For this analysis, we consider *p*-values of less than 0.016 to indicate statistical significance. This value is smaller (and thus more conservative) than the commonly used threshold of 0.05, because multiple comparisons (due to the different schools) require an adjustment of significance levels (Miller, 1981). We also compute a measure of effect size—that is, the magnitude of the treatment effect. The measure we use for effect size is Cohen's *d:* the difference between group mean gains divided by the within-group pooled standard deviation (Cohen, 1988). The effect size is computed for each school because the treatment effect depends on the school. An effect size of 0.2 is generally considered small, 0.5 is considered medium, and 0.8 is considered large (Cohen, 1992).

Experiment 1 results by school: Table 5 shows the results and *t*-test analysis for experiment 1, when the children were attending school. These results are illustrated graphically in Figure 4. The reading proficiency of the S2 children who used the Reading Tutor (the "treatment" group) improved significantly more than those who did not (the "control" group), as evidenced by larger gains in both fluency and TWS. The S3 treatment group significantly out-gained the control group in fluency, but not in spelling, although there was a positive trend. Finally, there was no significant difference in gains between the S1 treatment and control groups, for either test. Omitted from this analysis are five S1 children who were not present for the midway testing. Due to the small numbers, we did not break down the data to examine gains for each grade level within each school.

Experiment 2 results by school: Table 6 shows the gains (from mid-test to post-test) for experiment 2, when the children were not attending school. The results are illustrated graphically in Figure 5. Interestingly, there were negative fluency gains for the S2 children over the vacation, and these were significantly more dramatic for the control group than for the treatment group. We discuss this observation

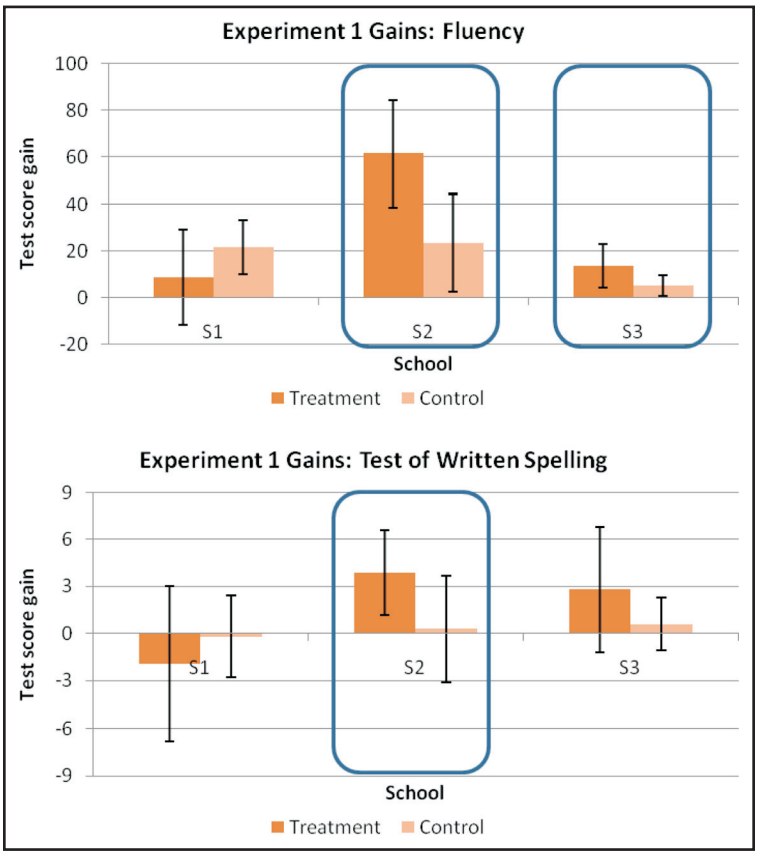

Figure 4. Comparison of treatment and control gains for Experiment 1, highlighting statistically significant differences.

in the *Discussion* subsection that follows. For the S2 children, the difference in TWS test score gains between the treatment and the control group was not statistically significant. Finally, there was no significant difference between the treatment and the control group in the other two schools, either for mean fluency or for TWS. Omitted from the analysis are two S1, two S2, and 10 S3 children who were absent for testing.

E. Discussion

Effectiveness of the Reading Tutor: The results provide evidence that, during the school term, the S2 students (and to a lesser extent, the S3 students) who used the tutor gained considerably more than those who did not use the tutor. Thus, the Reading Tutor was helpful for the S2 children. This is a positive outcome, since the S2 group most closely represents our target population of children from low-income families attending public school. The proficiency of the S1 children did not appear to be influenced by reading practice with the tutor. A possible explanation for this is that the S1 children might not have had much room to benefit from the tutor, since they were fluent readers going into the study. Observations of the three groups of students using the tutor showed that the S2 students appeared to be the most engaged overall, reading so enthusiastically that the room literally buzzed with noise. Some of the S1 students appeared to get bored easily—the

Table 6. Comparison of treatment and control gains for experiment 2.

Test	School	Treatment (Control-1st group, N=33)	Control (Tutor-1st group, N=37)	*t*-test comparison of treatment & control gains	
		Mean Gain (SD)		p-value	Effect size
Fluency (# words read correctly per min)	S1	0.3 (13.4)	−3.8 (22.6)	0.613	0.222
	S2	**−9.1 (17.1)**	**−39.8 (16.8)**	**<0.0001**	**1.816**
	S3	4.8 (6.0)	17.8 (27.0)	0.1321	−0.665
TWS (# words spelled correctly)	S1	2.0 (4.1)	2.9 (5.1)	0.6431	−0.197
	S2	0.4 (2.0)	0.6 (3.0)	0.858	−0.068
	S3	0.8 (2.4)	−0.3 (2.2)	0.3198	0.474

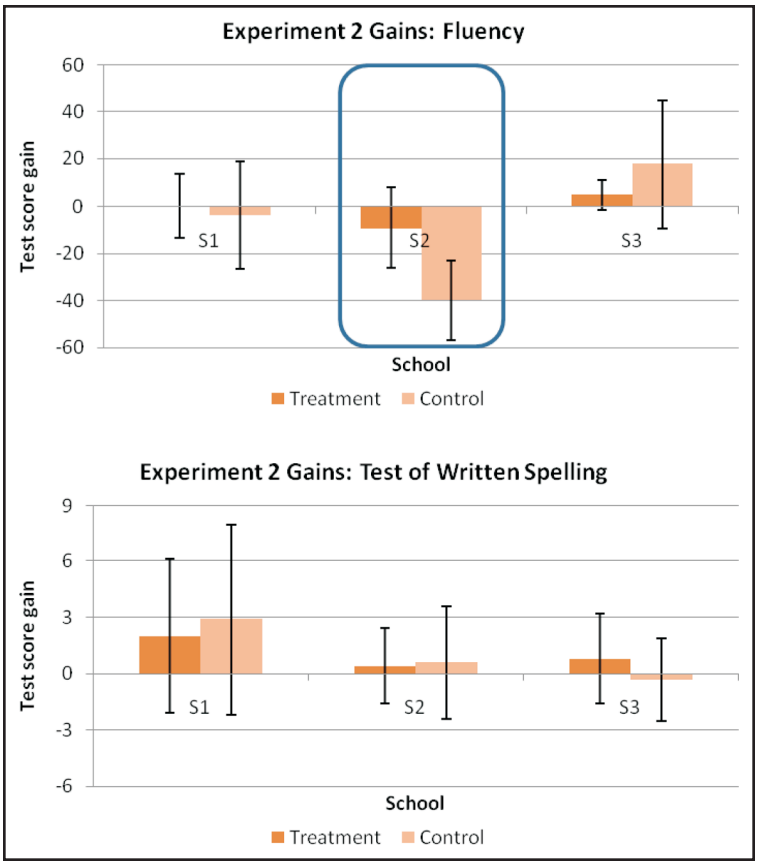

Figure 5. Comparison of treatment and control gains for Experiment 2, highlighting statistically significant differences.

researcher once noticed a child simultaneously reading a story book while using the tutor. As a group, the S3 students, who had a much lower proficiency in speaking and understanding English, in addition to having the lowest reading pre-test scores, had more trouble using the tutor than the other two groups: They required more frequent clarification of tutor instructions by the project staff (e.g., when a child appeared to be sitting idle and not responding to tutor prompts).

Loss in proficiency over vacation period: Of the statistically significant results highlighted in Figure 5, the negative gains of the S2 children in experiment 2 stand out. A possible explanation for this might be found in studies in the United States which have documented that reading achievement test scores for children from low-income families deteriorate significantly over the summer vacation (a phenomenon referred to as the "summer reading setback"), whereas those for children from middle-income families remain steady or increase slightly (Allington & McGill-Franzen, 2003). This trend has been attributed to the discrepancy in the reading opportunities and materials available to these two groups over the vacation period. In light of these studies, it is interesting to note that, for the S2 children, those who used the Reading Tutor did not deteriorate in reading ability as much as those who did not use it. However, the sessions with the Reading Tutor (totaling, on average, 11.5 hours of reading per child), without English class at school, were not enough to prevent negative gains.

Effect of pre-test scores: A complicating factor in the data analysis is the observed unequal average pre-test scores of the two groups, Tutor-1st and Control-1st, despite supposed random assignment of children to the two groups. Table 7 shows that this disparity is statistically significant for the S2 children. Higher pre-test scores can be the cause of greater gains (Stanovich, 2000), and so this difference in pre-test scores raises the question of whether the observed reading improvements are due to the use of the Reading Tutor, or to the higher pre-test scores. To investigate this, we computed the correlation between pre-test scores and gains, and we found no significant correlation. This suggests that the greater gains of the Tutor-1st group in experiment 1 are, indeed, attributable to the Reading Tutor, rather than to their higher pre-test scores.

Tutor usage: Another significant difference between the two experiments is that tutor usage in experiment 2 was much lower than in experiment 1, due to a higher level of absenteeism from the study during the school vacation. As Table 8 shows, S3 students' usage dropped to under a third of what it

Table 7. Comparison of pre-test scores for the Tutor-1st group and the Control-1st groups.

		Pre-test score		
		Tutor-1st (N=41)	Control-1st (N=42)	
Test	School	Mean (SD)	Mean (SD)	p-value
Fluency (# words read correctly per min)	S1	122.0 (45.9)	99.2 (33.9)	0.137
	S2	**65.8 (33.9)**	**26.2 (26.9)**	**0.0015**
	S3	18.6 (13.2)	12.1 (19.1)	0.308
TWS (# words spelled correctly)	S1	24.7 (9.7)	24.0 (9.6)	0.850
	S2	**11.1 (7.0)**	**4.3 (3.7)**	**0.003**
	S3	2.1 (2.2)	1.9 (3.1)	0.840

Table 8. Tutor usage in each experiment.

	School	Experiment 1 Mean (SD)	Experiment 2 Mean (SD)
Number of days of tutor use per student	S1	29.6 (12.0)	22.2 (9.4)
	S2	36.9 (2.4)	24.0 (11.7)
	S3	30.7 (2.8)	12.6 (3.9)
Total time spent reading with tutor per student (hours)	S1	12.4 (5.4)	11.9 (5.2)
	S2	18.6 (3.1)	11.5 (6.7)
	S3	17.3 (2.7)	6.8 (2.5)
Average daily time spent reading with tutor per student (minutes)	S1	22.9 (7.1)	32.6 (5.3)
	S2	30.1 (3.7)	26.6 (7.0)
	S3	33.9 (4.6)	31.9 (5.3)

was in the first half, although, on the days they did attend, the length of their Reading Tutor sessions were similar to what they were in the first half. Nineteen children who were absent for testing, either at the beginning or end of each experiment, are not included in this summary.

The reduced usage for S3 students may partly explain why there is no statistically significant effect of the Reading Tutor for S3 children in experiment 2. We found that there was a slight positive correlation between amount of usage and gains in the first experiment, but not in the second, and that usage was not a strong (statistically significant) predicator of gains in either experiment. This does not necessarily indicate that no relationship exists between amount of usage and test score gains. It is likely that we lacked the statistical power to detect this relationship due to the small sample size and the fact that school is a confounding variable. This is an example of where it would have been advantageous if we had been able to analyze the study as a cross-over study as originally planned, with each child serving as his or her own control.

7. Zambia: Pilot Study

The work in Zambia complements the prior studies in Ghana by investigating an in-school usage model and testing the tutor in a different English-speaking African country. ProjectEDUCATE, a nonprofit organization, introduced us to two under-resourced public schools in Mongu, Zambia. The schools had received donated computers and were enthusiastic to test the Reading Tutor. However, the Mongu District Education Board Secretary's office requested that we select only one school for the pilot test.

A. Goal

The goals of the Zambian pilot study were to answer the following questions:

1. *Computing infrastructure:* What is the state of the school's computer lab, how is it currently used, and can it feasibly support sessions with a computer-based reading tutor?
2. *Training Teachers:* How long does it take to train teachers to guide students in the use of the tutor?
3. *Children's response:* How do the children respond to the Reading Tutor?
4. *Test instruments and Reading Tutor content:* What test instruments and Reading Tutor content are appropriate for the Zambian setting?
5. *Feasibility of long-term study:* Would a remote partnership between the school and our research group be a feasible model for a longer-term controlled study?

B. Methodology and Implementation

The selection of the school for the pilot test was done after meeting with the headmasters and teachers at both schools and assessing the state of the computer labs and the potential for a successful study. Subsequently, the pilot study consisted of conducting interviews with teachers at the selected school, providing training for the teachers, and making qualitative observations of teachers and students as they used the Reading Tutor. We also explored with the teachers possible details of a longer controlled study.

C. Results and Observations

Both schools had labs with roughly 20 266 MHz Pentium II computers with 64–128MB of RAM and 10GB hard drives. Some teachers from each school had taken a computer skills training course when the computers were donated, but had not had the opportunity for additional training or guided practice. The schools did not have Internet access, and the computers were used primarily by teachers for typing exam questions. Given the large class sizes (ranging from 50 to more than 100 students) and the strict timetable, the teachers could not feasibly use the lab to teach all students about computers. Some computers at both schools were not functioning due to broken keyboards, mice, and power strips; some computers were not being protected from dirt during the dusty winter months; power outages were a daily occurrence; and for one school, even maintaining electricity for the computer lab was a challenge due to limited financial resources. For the pilot study, we selected the school with better maintained equipment and a higher likelihood of maintaining communication by telephone and e-mail.

We trained three teachers to use the Reading Tutor. The hour-long session covered the educational features of the tutor, as well as administrative tasks, such as managing users. After basic instruction and some time to practice on their own, the teachers were able to guide students in using the tutor. They would often give feedback to the children as a complement to the tutor when the students had difficulty reading stories. For example, they would instruct the children to click for help when they needed it, or they would sometimes correct a mispronounced word that the tutor did not detect. We think this involvement of teachers in the early stages as the child gets used to the tutor could be an important part of longer-term use of the Reading Tutor in a school setting. The teachers especially appreciated the ability to track their students' performance using the tutor.

We observed a group of 11 children in grades two through four as they read one or two stories from the tutor. The students were selected by the teachers and had varying levels of reading ability, English comprehension, and speaking fluency. All of the students except one were completely new to computers. We introduced them, as a group, to the basic components of the computer, and then we gave them the opportunity to demonstrate use of the mouse and keyboard to each other. We provided verbal instruction to students individually as they began reading stories from the Reading Tutor. Some grade-two students seemed to have difficulty understanding English, since English is introduced as a language of instruction only in grade two, as a part of the Zambian Ministry of Education's initiative to encourage basic literacy by teaching in a familiar language in the first year of school. The students enjoyed using the Reading Tutor; when we returned to the school on another day to meet with the teachers, the group of students was using the word-building exercises in the Reading Tutor on their own time.

Figure 6. Teachers and a child test the Reading Tutor in Mongu.

Figure 7. Students in Mongu using word-building exercises as a group.

Building on the studies in Ghana, which focused on assessing reading with the same standard measures that have been used with previous studies with the Reading Tutor, we were able, in Zambia, to discuss with the teachers additional reading assessment options for a longer-term study. We learned that, through the Zambia Primary Reading Programme (PRP), the students' literacy levels are measured by reading standardized storybooks aloud to their teachers. Each color-coded book is associated with a given reading level. Once the teacher determines that the child can successfully read at a given level, he or she moves the child up to a higher level reading group with a different set of books. The teachers were interested in engaging the students with the computers in a way that would support curricular requirements from the Ministry of Education, and this was also emphasized to us by the Ministry of Education officials. We also saw that several of the existing Reading Tutor stories had little relevance to children's lives in Mongu.

Together with the teachers, we explored the feasibility of a year-long, in-school controlled study using the Reading Tutor. The teachers suggested that a random subset of the children in grades two through four could be selected to participate in a controlled study. They explained that students in these grades have 60 minutes of reading class per day and suggested that the intervention group of students could spend 30 minutes of that time working with the Reading Tutor, with teacher supervision, while the control group of students would remain in class. Thus, it would be logistically feasible to incorporate a study into the school schedule. However, it was clear that there would be several challenges in conducting this project as a remote field study. Communication is difficult, given the school's limited Internet access and frequent disruptions in telephone communications. Success would depend on the teachers taking ownership of the project as a result of their own enthusiasm; however, from our experience in Ghana, we realized the importance of close communication and collaboration to ensure that the individuals running the study have the needed support. We hoped that maintaining communication with local contacts would help address some of the expected challenges. However, it has not yet been feasible to conduct a longer-term structured study, even though we are told that some children at the school have been using the Reading Tutor. The experience in Zambia so far has helped to identify some of the challenges with in-school use of a tool such as the Reading Tutor.

8. Lessons Learned

The lessons gleaned from our experiences in Ghana and Zambia can be broadly categorized into those about study implementation, and those about longer-term viability of automated tutoring for this setting. The lessons captured below are particularly relevant, due to the current dearth of literature on the evaluation of educational technology in African contexts. We believe that this is a fertile and important area for further research, and we recognize the value of discussing not only technical results, but also lessons about process, in order to encourage and assist further work in this area.

A. Study Implementation

1) Building relationships

As is well-appreciated in this field of research, an important requirement for running these studies was the process of developing partnerships at each stage in the project. Significant time must be devoted to building relationships and developing a shared vision. Researchers have articulated this requirement for a variety of contexts—e.g., Schwartzman and Parikh (2007). An interesting feature of the project described in the current paper is that it involved, at different stages, both field research by the authors and remote collaboration with implementation partners. In developing the various partnerships at each stage, we found that phone conferences can be a useful tool, but some face-to-face meetings are essential, particularly in the early stages of project planning. A staged implementation, as in a pilot study followed by a controlled study, helps to distill key questions to ask, refine design and implementation decisions, and identify potential problems.

2) Logistics

We learned that it was important for someone involved in the local, day-to-day running of the project both to have significant decision-making power and to feel ownership of the project. This individual must have the ability, for example, to replace equipment or interface with representatives of the school administration. Otherwise, problems can easily stall progress. It is also essential to have access to some local technical expertise to troubleshoot and repair problems—building this local support base during the pilot studies is crucial.

For the controlled study in Ghana, we found that the remote collaboration required regular, sometimes daily, communication among the project partners; e-mail, instant-messaging, and VoIP were cost effective and feasible means of achieving this.

Not surprisingly, we learned that a process that requires a significant change in behavior and extra work on the parts of parents, such as having the children come to school or participate in a study during a vacation, is hard to sustain and should be avoided if possible. However, it was also clear that unexpected situations are bound to arise for any study that involves cross-continent collaboration, so flexibility and the ability to adjust the study design if necessary is essential. For example, in the controlled study in Ghana, the second half of the study had to be held during the school vacation, despite the fact that this was not the original plan.

B. Viability of the Automated Reading Tutor for this Context

1) Impact of prior knowledge and experience

A key lesson was that, even without prior computer experience, the participating children were quickly able to acquire the skills needed to use the tutor. In general, they were excited about using the computer and about the interactive features of the Reading Tutor. Assistance from the project staff (in Ghana) or from the teachers (in Zambia) helped those children who were initially nervous about computer use or about reading in English. In both locations, the children's natural curiosity overcame any initial apprehension with the unfamiliar technology.

We noticed that children with a basic foundation in English and not much prior experience with computers, such as the S2 children in Ghana, were easily engaged with the tutor. It was clear that insufficient familiarity with the English language was a challenge for some, particularly the S3 children in Ghana and some of the grade two students in Zambia. For children who did not yet understand English well enough to benefit from an automated tutor that uses only English, a tool that bridges between the local language and English, perhaps by giving oral prompts or explaining words in the local language, might have been better. A challenge to take into consideration, however, is that, in this context, children are often not literate in their native language either, so the issues of literacy and language learning are intertwined. The question of whether chil-

dren learn to read first in their native language or in the country's official language is an important issue in the discourse on primary education in Africa. Pedagogical findings support the former, as discussed by Clegg et al. (2003), but many practical issues often result in the implementation of the latter, particularly in urban areas where several languages are spoken.

Finally, we noticed that the S1 children who were already fluent readers and experienced with computers seemed to get bored and distracted easily when using the Reading Tutor. This might have been because the Reading Tutor displays the story being read one sentence at a time, and there would sometimes be a short delay in loading the next sentence. For a fluent reader, even this short delay was noticeable and sometimes frustrating.

2) Usage models

Although the Reading Tutor is designed for use by a single user at a time, we noticed that, in both pilot studies, children would gather around a single computer and try to help each other. This also happened to a lesser extent during the controlled study in Ghana, and suggests that we should investigate multi-user scenarios.

In running the Ghana studies, transportation of the children was the greatest expense, so although scheduled out-of-school use in an ICT center was the model chosen for the controlled study, its viability as a long-term usage model will depend on factors such as the proximity of appropriate ICT centers to the schools. As we learned in Zambia, there are also many challenges to be addressed for an in-school usage model for under-resourced public schools, even when the school already has a computer lab. It is clear that a careful analysis of the particular context would need to inform decisions about what usage models to adopt, and that clear steps would need to be taken to address the particular challenges of that context.

3) Usability

There are several usability improvements that can be made to the Reading Tutor to reduce the required technical support, particularly in a developing community setting. These features would apply to any PC-based intervention.

- Installation must be easy and straightforward.
- Customization must be easy (both for adding local content and to control for the installation footprint for machines without much hard disk capacity). Although it is straightforward to add new stories to the Reading Tutor, the process of narrating these new stories after adding the text can be rather tedious.
- An easy administrative interface is needed for controlling options such as level of logging, again to deal with limited-capacity machines.

4) Summary

The studies showed that automated tutoring with the Reading Tutor holds significant promise for helping children improve their reading. For this to be sustainably exploited in a developing community, several challenges need to be addressed. The most important challenge is designing creative usage and support scenarios to enable children in under-resourced schools to benefit from automated tutoring despite the resource constraints and lack of technical expertise and infrastructure faced by the schools. A further consideration is that the Reading Tutor in its current form is a research prototype and is not readily available for non-research use. In addition, as discussed above, there are features which could be included that would make such a tool even better suited to a developing community setting. Thus, a useful development might be an open-source tool that is freely available to schools and supported via a public-private partnership within the country in question.

To address the needs of various contexts within a community with differing levels of available resources and support, it might be useful to consider a continuum of literacy-supporting tools, beginning with simple exercises that run on platforms that are truly ubiquitous, such as the mobile phones exploited in prior related work, and leading up to the more sophisticated automated tutors for personal computers.

9. Conclusions and Future Work

This paper presents our initial investigations into the viability and effectiveness of a computer-based reading tutor in improving English literacy among children in Ghana and Zambia, particularly those attending under-resourced public schools. This work is a useful contribution to the discourse on ICT in development, both because it demonstrates that there is promise for the effectiveness of the approach and because of the practical lessons

regarding the implementation of the study. We have presented an initial proof-of-concept investigation. Many additional questions would need to be explored to understand the potential for large-scale application of these technologies.

Follow-up work for our project includes pursuing the goal of conducting a year-long study to test the feasibility of an in-school usage model in a developing community setting. This study would both measure the children's reading gains over an entire school year of using the Reading Tutor and compare these gains to those obtained with a non-technological approach to guided reading practice. The study would also investigate the feasibility of incorporating teachers closely into this work.

Additionally, we will continue to develop an understanding of what features would be required for a continuum of literacy-enhancing tools developed specifically for use by children in developing communities in Africa and elsewhere. What needs can be met with lighter-weight tools (e.g., mobile phones) versus computer-based tools? Others in our research group have recently begun this process through an initial project in Tanzania that resulted in the design and implementation of a prototype mobile phone-based literacy game for children and an accompanying Web-based content authoring tool for teachers (Abimbola et al., 2009). There is significant scope for further research on the role of computing technology in improving child literacy in developing communities. ■

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References

Abimbola, R., Alismail, H., Belousov, S. M., Dias, B., Dias, M. F., Dias, M. B., et al. (2009, August). iSTEP Tanzania 2009: Inaugural experience. (Carnegie Mellon University, Robotics Institute Technical CMU-RI-TR-09-33). Retrieved April 25, 2010, from http://www.ri.cmu.edu/publication_view.html?pub_id=6422&menu_code=0307

Adams, M. J. (2006). The promise of automatic speech recognition for fostering literacy growth in children and adults. In M. C. McKenna, L. D. Labbo, R. D. Kieffer, & D. Reinking (Eds.), *International handbook of literacy and technology, Volume 2.* Mahwah, NJ: Lawrence Erlbaum Associates.

Allington, R. L., & McGill-Franzen, A. (2003, September). The impact of summer setback on the reading achievement gap. *Phi Delta Kappan, 85*(1), 68–75.

Banerjee, A. V., Cole, S., Duflo, E., & Linden, L. (2007, August). Remedying education: Evidence from two randomized experiments in India. *Quarterly Journal of Economics, 122*(3), 1235–1264.

Clegg, J., Ogange, B., & Rodseth, V. (2003, April). Evaluating digital learning material for English language development in African primary classrooms. *IMFUNDO KnowledgeBank Paper.* Retrieved April 25, 2010, from http://imfundo.digitalbrain.com/imfundo/web/papers/refpapers/?verb=view

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates.

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112,* 155–159.

Deno, S. L. (1985). Curriculum-based measurement: The emerging alternative. *Exceptional Children, 52*(3), 219–232.

Hasbrouck, J. & Tindal, G. A. (2006). Oral reading fluency norms: A valuable assessment tool for reading teachers. *The Reading Teacher, 59*(7), 636–644.

Kam, M., Agarwal, A., Kumar, A., Lal, S., Mathur, A., Tewari, A., et al. (2008, February). Designing e-learning games for rural children in India: A format for balancing learning with fun. *Proceedings of the 7th ACM Conference on Designing Interactive Systems* (DIS '08), 58–67.

Kam, M., Kumar, A., Jain, S., Mathur, A., & Canny, J. (2009, April). Improving literacy in rural India: Cellphone games in an after-school program. *Proceedings of the 3rd International Conference on Information and Communication Technologies and Development* (ICTD 2009), 139–149.

Kozma, R. B. (2005, November). Monitoring and evaluation of ICT for education impact: A review. In D. A. Wagner, B. Day, T. James, R. B. Kozma, J. Miller, & T. Unwin (Eds.), *Monitoring and evaluation of ICT in education projects: A handbook for developing countries* (pp. 11–18). Washington, DC: infoDev/World Bank. Retrieved April 25, 2010, from http://www.infodev.org/en/Publication.9.html

Larsen, S. C., Hammill, D. D., & Moats, L. C. (1999). *Test of written spelling.* Austin, TX: Pro-Ed.

Lipson, M., & Wixson, K. (2004, August). Evaluation of the BTL and ASTEP programs in the Northern, Eastern, and Volta regions of Ghana. Report prepared by the International Reading Association for The Education Office, USAID/Ghana. Retrieved April 25, 2010, from http://www.reading.org/General/CurrentResearch/Reports/GhanaReport.aspx

Louw, J., Muller, J., & Tredoux, C. (2008, February). Time-on-task, technology and mathematics achievement. *Evaluation and Program Planning, 31*(1), 41–50.

Miller, R. G. (1981). *Simultaneous statistical inference* (2nd ed.). New York: Springer Verlag.

Mostow, J. & Aist, G. (2001). Evaluating tutors that listen: An overview of Project LISTEN. In K. D. Forbus & P. J. Feltovich (Eds.), *Smart machines in education* (pp. 169–234). Cambridge, MA: AAAI Press/The MIT Press.

Mostow, J., Aist, G., Huang, C., Junker, B., Kennedy, R., Lan, H., et al. (2008). 4-Month evaluation of a learner-controlled Reading Tutor that listens. In V. M. Holland & F. P. Fisher (Eds.), *The path of speech technologies in computer assisted language learning: From research toward practice* (pp. 201–219). New York: Routledge.

National Institute of Child Health and Human Development (NICHD). (2000). *Report of the National Reading Panel. Teaching children to read: An evidence-based assessment of the scientific research literature on reading and its implications for reading instruction* (NIH Publication No. 00-4769). Washington, DC: U.S. Government Printing Office. Retrieved April 25, 2010, from http://www.nichd.nih.gov/publications/nrp/smallbook.cfm

Poulsen, R., Hastings, P., & Allbritton, D. (2007). Tutoring bilingual students with an automated Reading Tutor that listens. *Journal of Educational Computing Research, 36*(2), 191–221.

Reeder, K., Shapiro, J., Early, M., Kendrick, M., & Wakefield, J. (2005). The role of L1 in young multilingual readers' success with a computer-based reading tutor. *Proceedings of the Fifth International Symposium on Bilingualism.*

Schwartzman, Y. & Parikh, T. S. (2007). Establishing relationships for designing rural information systems. *CHI '07 Extended Abstracts on Human Factors in Computing Systems.* New York, NY: ACM. Available at doi= http://doi.acm.org/10.1145/1240866.1240909

Senn, S. (1993). *Cross-over trials in clinical research.* Chichester, UK: John Wiley & Sons.

Stanovich, K. E. (2000). *Progress in understanding reading: Scientific foundations and new frontiers.* New York: Guilford Press.

UNESCO. (2005). *Education for All global monitoring report 2005—Education for All: The quality imperative.* United Nations Educational, Cultural and Scientific Organization (UNESCO) Publishing. Retrieved April 25, 2010, from http://www.unesco.org/en/efareport/reports/2005-quality/

Wagner, D. A. (2005, November). Monitoring and evaluation of ICT4E: An introduction. In D. A. Wagner, B. Day, T. James, R. B. Kozma, J. Miller, & T. Unwin (Eds.), *Monitoring and evaluation of ICT in education projects: A handbook for developing countries* (pp. 5–9). Washington, DC:

infoDev/World Bank. Retrieved April 25, 2010, from http://www.infodev.org/en/Publication.9.html

Wagner, D. A., Day, B., & Sun, J. (2004, March). Information technologies and education for the poor in Africa (ITEPA). *IMFUNDO KnowledgeBank Paper.* Retrieved April 25, 2010, from http://imfundo.digitalbrain.com/imfundo/web/papers/refpapers/?verb=view