Facilitating Help-Seeking for K-2 Students in Rural Schools in Tanzania

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Abstract

Sub-Saharan Africa is the world's fastest growing region with regards to the adoption of mobile technologies with three quarters of the population owning a mobile device[1]. The region is also currently undergoing an education crisis with over 32 million out-of-school children, and over 80% of school-enrolled children not meeting minimum proficiency in math and reading assessments. Therefore, interested organizations and governments have attempted to tackle this issue by introducing mobile educational technologies to supplement, and sometimes replace traditional classroom education. Some of these initiatives have shown positive learning gains for students, often attributing these outcomes to children's innate curiosity to teach themselves the content, context-aware curriculums, as well as peer support and collaboration in the learning process. Indeed, peer support should be utilized and encouraged to maximize the efficacy of educational technologies. Collaborative peer learning leads to increased test scores, cognitive activity, motivation and enthusiasm, and satisfaction over individualized learning settings. While knowledgeable adults can provide (or be trained to provide) adequate domain knowledge support for children learning with technology, this often comes at the expense of the benefits that peer collaboration brings to the learning process, especially in regions where peer-peer collaboration may not be encouraged by teachers such as some cultures in Tanzania.

To begin this thesis, I conducted two research studies to understand how peers support each other in rural, low-resource contexts in Tanzania. In the first study, I deployed a tablet-based educational technology in different social contexts; in school and at home, in the presence or absence of adults, with shared or individual tablets, and in the presence or absence of other knowledgeable children. Based on insights from video observations and interviews, I found that students needed three types of support to successfully engage with the tablet-based learning technology: digital literacy support, application specific support, and domain knowledge support. Peers provided digital literacy, and application support primarily by modeling correct behaviors or selecting answers for their peers. In the presence of a teacher however, peers did not collaborate at all, and depended entirely on teachers for support.

Following these results, I conducted an experimental study where I assigned and trained group leaders to provide adequate peer support while learning with technology. I varied the experimental conditions by making the presence of the leader public in some groups but not in others. I found that group leaders provided adequate and persistent support only in the public condition due to the social expectation of help-giving from their peers. Results from this experimental study showed that with adequate knowledge and training, peers can provide support for each other in this cultural context. However, this arrangement did not promote a culture of help-seeking, help-giving, and collaboration between all members of the group as a whole, and the leader's new authority position caused them to exhibit behaviors similar to a teacher such as verbally and physically reprimanding students for disturbing the group, interrupting student sessions, and seizing student tablets as disciplinary measures.

To complete my thesis, I explored the design of a system intervention that fostered more equitable helping and collaborative student behaviors by designing a rule-based struggle detection system that automatically detects the kind of support that a student needs, and offers them suggestions to seek for help from another student in the group who has mastered that task. This intervention is based on an Intelligent Novice Model, where students are allowed to engage in productive struggle, and feedback is

[1] https://www.pewresearch.org/global/2018/10/09/majorities-in-sub-saharan-africa-own-mobile-phones-but-smartphone-adoption-is-modest/

delayed until the struggle is detrimental to the student experience (unproductive floundering). In this system, every student became a potential helper by navigating an application successfully or scoring well on an activity. I conducted an experimental study in a school located in a rural village in Tanzania over a one-month period, using mixed methods approaches to understand differences in students' helping behavior, their interaction patterns and performance differences on the learning device, how they handle struggle while learning, as well as any changes in their classroom behavior as a result of the increased collaboration between group members during the experimental sessions. Such a study would be incomplete without gaining the perspectives of teachers who have to deploy and incorporate these technologies into their teaching practice. Therefore, I also present insights from observing classrooms and interviewing teachers and administrators in rural Tanzanian classrooms on the socio-cultural ideologies that influence their disposition towards peer-peer collaboration in the classroom. This thesis contributes to research on applying learning science principles in understudied contexts, designing feedback mechanisms for learning systems, and understanding the effects of teaching students such behaviors on normal student-student, and student-teacher interactions.

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Many people do not know (or have forgotten) that I started my PhD journey at the University of Maryland in Baltimore County. After three years, I left that program with a Masters degree and restarted my journey at Carnegie Mellon because I really wanted to conduct research on education technology but had no faculty support. The decision to leave that program was difficult but it taught me so many wonderful lessons that made my PhD journey at CMU much less emotionally daunting compared to most of my peers. Having no faculty support meant that I had no funding for any education-related projects. This allowed me the opportunity to learn to design experiments, write IRB's, motivate participants with little funding, write papers, and fight for projects that were truly dear to my heart all on my own. Of course, I had very little actual research experience and made every imaginable rookie mistake. Every single paper I wrote in my first two years got rejected. 'Reviewer 2' commented on my first paper submission that it was an "absolute waste of their time". Did they know how much effort, emotional energy, and money from my ($20,000 pretax) annual PhD stipend went into that project? These rejections taught me to disconnect my self-worth from my work before I ever set foot at the HCII and taught me so much empathy and respect for novice researchers who are just doing their best to communicate their work. It taught me to celebrate myself after paper submissions regardless of the outcome, made me excited about becoming a better researcher with more practice, taught me to always give 110% to my work so I could be proud of myself regardless of the outcome, and not take most criticisms of my work personally.

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Contents

Chapter 1 – Introduction

The percentage of students enrolled in primary schools in Sub-Saharan Africa has been steadily increasing in the last 20 years due to concerted efforts from national governments to make education more accessible to their citizens[2]. However, the number of out-of-school children in both rural and urban regions have also been increasing at rates that traditional schooling infrastructures cannot accommodate. Current estimates by UNESCO report that there are over 63 million out-of-school children in the world, with over 50% living in Sub-Saharan Africa[3]. Those estimates have been increasing over the last few years despite government commitments to address the issue. This education crisis is not limited to out-of-school children – of those enrolled in school, less than 20% score above minimum proficiency on math and reading assessments[4]. Reasons for these educational disparities include the lack of access to skilled teachers [129], school infrastructure, and resources such as textbooks [157] in rural regions. The opportunity costs for educating children in rural communities are also higher. Families often depend on their children's labor for survival, and may not value formal educational curricula that are not directly related to their local community vocations [107].

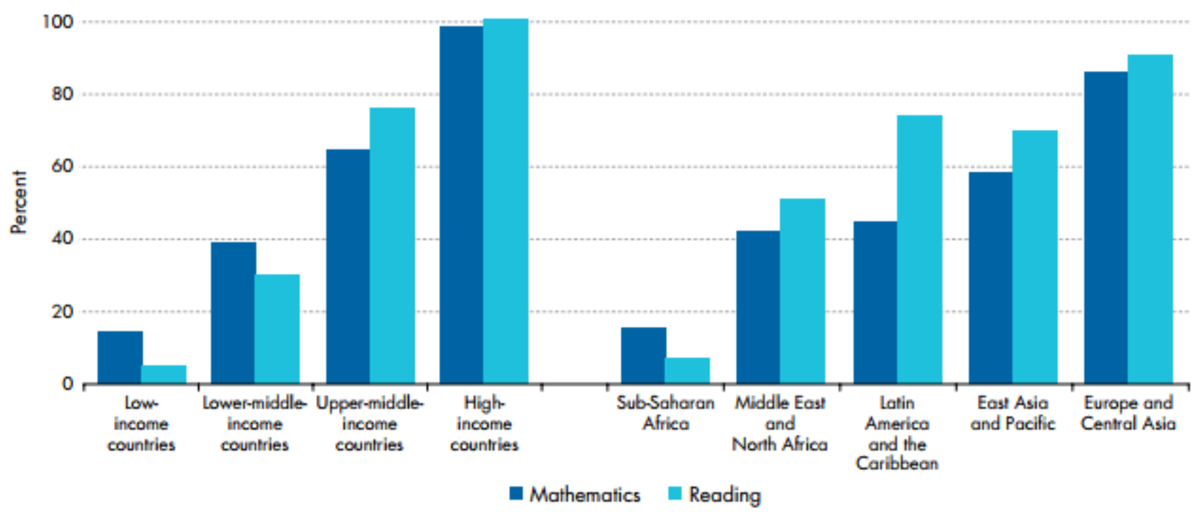

Figure 1: Percentage of primary school students who pass a minimum proficiency threshold in Math and Reading
https://www.brookings.edu/blog/africa-in-focus/2017/10/06/figures-of-the-week-africa-education-world-development-report-2018/

As a result, several organizations and governments have attempted to address these challenges by deploying educational technologies (EdTech) to students in and out of schools. This solution is particularly attractive as it is cheaper than traditional schooling infrastructure, scales much faster, and avoids the difficulties of finding and hiring qualified teachers in rural areas [29]. Unfortunately, several of the initial large-scale technology deployments have failed to meet their intended goals (e.g. the One Laptop Per Child initiative) due to a lack of understanding of the local context of the end users, as well as a lack of technical infrastructure and support for these initiatives [193,210].

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[2] https://data.worldbank.org/indicator/SE.PRM.NENR?end=2017&locations=ZG&start=2000

[3] http://uis.unesco.org/sites/default/files/documents/fs48-one-five-children-adolescents-youth-out-school-2018-en.pdf

[4] https://www.brookings.edu/blog/africa-in-focus/2017/10/06/figures-of-the-week-africa-education-world-development-report-2018/

Beyond the pragmatics of cultural norms and values, there is a significant amount of work in the Information and Communication Technology for Development (ICTD) scientific community that identifies important factors that impact the effectiveness and adoption of educational technology across cultures, particularly in emerging economies. These factors include issues of physical resources like facilities and computing power, technology literacy once computing resources are available, as well as home language literacy. For example, an evaluation of the efforts of large charity programs that donate technology such as laptops in mass has shown that these initiatives can fail due to lack of consideration of local conditions. Therias et al. evaluated the program Blue Sparrow, which donates refurbished laptops in developing countries for educational purposes. They found hindrances to acceptance and success because of issues such as difficulty connecting to the Internet, fears of having technology stolen or damaged, lack of clearly defined goals for the program, and lack of familiarity [193]. The authors maintain that “simply providing more technology does not inevitably lead to positive changes" in addressing educational disparities in these socio-cultural contexts.

Despite the failures of some of the earlier initiatives, several studies have shown that when deployed using a bottom-up approach, where the social, cultural, and infrastructural needs of the end users are prioritized, educational technologies can indeed lead to positive learning gains e.g. [28,55,198]. These studies often attribute these outcomes to children’s innate curiosity to teach themselves the content, context-aware curriculums, as well as *peer support and collaboration in the learning process*. The role that peers potentially play in the success of these technology initiatives is supported by numerous scientific studies. The benefits of peer-peer collaboration and help-seeking in the learning process includes increased cognitive activity [71], increased motivation and satisfaction [201], increased enthusiasm for learning over individualized learning settings [136], and higher literacy scores [66].

Research studies show that students who actively monitor their own learning and seek for timely help learn more effectively with education technologies [6,160], and in traditional classroom environments [10,88,169]. It is a key self-regulatory skill for children to know the appropriate method, or the right timing to seek for help from their peers [134,135]. Although there is general consensus that peer interactions are beneficial, organizations who deploy learning technologies in rural contexts have not necessarily designed them to scaffold these peer interactions, relying on children’s innate curiosity and expecting that natural leaders will emerge and support their peers without the need for a knowledgeable adult [124,142]. These assumptions are generally made without consideration of the helping and collaboration culture of the end users, and therefore may not foster these beneficial peer-peer interactions.

Rural villages in Tanzania are an appropriate setting to deploy educational technologies specifically built with scaffolding for peer interactions as there is dire need for improved educational outcomes, and the everyday cultural practices are often more collaborative than individualistic. Located in East Africa, Tanzania has a population of about 58 million people, with 44% less than 15 years old[5]. With such a high population of young people, the Tanzanian government has been focused on providing adequate education, from pre-primary to secondary school, to prepare them to be gainfully employed. Unfortunately, these efforts have been met with several challenges at all the different education levels starting from pre-primary education. Although pre-primary education has been part of the formal education system since 1995, it is completely optional which decreases the likelihood of attendance, and

[5] http://worldpopulationreview.com/countries/tanzania-population/

reduces the primary school readiness of children in rural communities strapped for economic resources. Even with these enrollment challenges, the quality of pre-primary and primary education in rural areas in Tanzania is much less than optimal. Reports show that the teacher to student ratio in Tanzanian rural villages range from 1:82 to 1:98, only 9% of primary teachers have adequate professional qualifications, teachers are often absent from school, and while parents are able to support with building schools and donating food, they often lack the competence to supplement formal education at home [127,128]. **Therefore, in this socio-cultural context, there is real need for educational interventions to supplement traditional classroom instruction and collaborative educational technologies are a potential solution**. **These technologies may need to be designed with the expectation that peers will need to support each other in the likely absence of knowledgeable adults. In a context where teachers are often overwhelmed with class sizes or unavailable to teach, education technologies can supplement instruction to allow teachers work with smaller group sizes, or substitute traditional instruction when teachers are unavailable.**

To investigate and understand student help-seeking behaviors in a rural Tanzanian context, my prior studies investigated the following research questions (discussed in more detail in each study chapter):

Study 1, Research Questions:

- What kinds of support do children need while learning with education technologies, and do other children provide all of them?
- How do children engage with learning technologies in home vs school environments?

Study 2, Research Questions:

- To what extent do knowledgeable students take on the role of a leader within a group of learners, when either privately or publicly assigned the authority to do so?
- Do factors such as gender and close friendships affect the kinds of support that assigned leaders provide in this cultural context?

Results from both studies provide evidence that unassigned and unprompted leadership is rare in the Tanzanian rural communities that I investigated (although natural helpers may be more common in other cultural contexts) [200]. Students freely engaged with their adjacent peers in the absence of a teacher, but rarely took up the responsibility of providing help to non-adjacent peers, nor persisted long enough to help with difficult issues without explicit leadership assignment. On the contrary, students who were assigned as helpers consistently persisted through difficult problems with their peers, sought external help when they couldn't solve problems, and their peers consistently reached out to the them for their needs and on behalf of other struggling students. I even observed a few cases where students collaborated with one another – taking turns to try out different solutions to a question when the instructions were unclear.

These results show that with publicly available leadership assignment and proper scaffolding/training in schools, students in this cultural context can provide much needed support for their peers, however, designating individual students as group leaders placed too much of the helping burden on them. This leadership designation also had some negative impact to the group rapport, with student leaders enforcing discipline both verbally and physically to students who did not conform to group norms. Furthermore, as more learning applications are developed to accommodate additional knowledge components with different input modalities, it is unreliable to train only one (or a few students) to provide all the different kinds of support that their peers need. Finally, this individual-leader group design wastes the opportunity of utilizing other knowledgeable students within groups to provide peer support and promotes a culture of top-down knowledge transmission rather than a true collaboration.

Based on reports that high-performing students model desirable learning behaviors and help keep their lower-achieving peers on task, e.g [83], one might assume that only the highest achieving students be selected as peer tutors. However, other studies provide evidence that high and low-performing students equally benefit from being assigned the role of a peer tutor [56,93,118,211,214], especially when such interactions are adequately scaffolded [34,141]. Regardless of student ability, peer tutoring allows students to reflect and build on their own knowledge, and motivates them to take control of their learning [38].

In this thesis, I build on this prior work by taking advantage of the capabilities of the learning technology to facilitate timely and appropriate peer-peer help-seeking and collaboration within learning groups in rural Tanzanian classrooms. My work builds on a model (Intelligent Novice Model) of providing students with timely feedback and interventions to achieve a model of desired performance. Using a gesture recognition algorithm, the system can detect when a student does not have adequate digital literacy, application navigation skills, or domain knowledge to engage with a learning application. After allowing some productive and often beneficial struggle, the system suggests that the student collaborate with another student who has navigated the application successfully in the past. By monitoring the performance scores of students within the group, struggling students can be directed to peers who have mastered the domain knowledge they need help with. Within a short period of time, every student in the group can potentially become a helper to support students' digital literacy and domain knowledge needs, and random helper assignment ensures that every qualified helper for a given problem can be called upon with equal probability. Finally, this system intervention discourages off-task behavior and boredom by redirecting students to collaborate with their peers after a period of unproductive activity.

My **dissertation study research questions** are as follows:

- What are the socio-cultural ideologies that influence teachers disposition towards peer-peer collaboration in rural Tanzania?
- How are peer-peer collaborative practices demonstrated (if at all) in rural Tanzanian classrooms?
- What are some peculiar struggles teachers and students experience in this learning context?
- Is technology-mediated provision of appropriate peer help resources effective for improving help-seeking, learning, and collaboration among school students in Tanzanian rural areas learning using education technologies in the absence of knowledgeable adults?
- Does introducing collaborative behaviors that potentially contradict normal pedagogical practices cause the students to behave differently in the classroom, and what are the consequences for such behaviors?

This research study was executed as a mixed-methods experimental study design conducted over a one-month period, collecting data from teacher interviews, classroom observations, and a treatment vs control experimental study where groups of students are provided with individual tablets preloaded with the learning system. This dissertation study includes data from 139 experiment sessions, 39 classroom observations from two schools, and 24 interviews with school administrators from four schools. In the experimental study, students interacted with the system for an hour a day (or for the length of their typical class period). The experimental group was provided with the help-seeking system intervention, while the control group was giving the learning system and informed that they were allowed to were observed and collected via video observations without the presence of adults, student interaction behavior and performance were collected and quantitatively analyzed from the system logs, and classroom interactions were gathered via observing daily classroom sessions with teachers in the absence of the learning technology.

I investigated the following hypotheses for the experimental study:

- H1 – Student Interactions:
    a) Students in the experimental group will have significantly increased interactions with non-adjacent peers compared to the control group
- H2 – Error Recovery:
    a) Students in the experimental group will have higher activity completion rates (adjusting for activity types) compared to the control group
    b) Students in the experimental group will have significantly increased selections of activities that are *perceived to be more difficult* compared to the control group.
- H3 – Learning:
    a) Students in the experimental group will have a significantly higher number of activities mastered within the learning system compared to the control group
    b) Students in the experimental group will demonstrate higher pre- vs post-test gains compared to the control group

Overall, this thesis contributes to the scientific literature on the effectiveness of peer-peer help-seeking in learning environments in rural Tanzanian contexts, designing systems specifically to support peer-peer help-seeking, and understanding any consequences of normalizing help-seeking behaviors on a classroom culture where it is often prohibited.

Chapter 2 – Background

I have organized this section by highlighting the benefits of teaching reading and handwriting in early childhood development and giving an overview of how adults and peers support children in the learning process (Part 1). I follow that by discussing how cultural groups can be defined, providing some insights about the current state of early education in Tanzania, and elaborating on Tanzanian cultural norms and teaching practices that can impact student help-seeking behaviors (Part 2). Finally, I provide an overview of different educational technologies that have been intentionally designed to provide intelligent tutoring and scaffolding for peer interactions, and the different factors I considered in the design of our own system including timing of feedback, interruptions, etc. (Part 3).

Part 1 – Student support in early reading and writing instruction

2.1.1 Teaching Early Reading and Writing Skills

It is widely accepted that teaching reading skills is a critical component of any formal education program, however, there are different approaches to how reading should be taught. The most common teaching methods include letter shapes, letter, words, sentences, and a combination of these methods [181]. Reading allows students to learn "about other people, about history and social studies, the language arts, science, mathematics, and the other content subjects that must be mastered in school" [110]. It allows students to navigate the world as global citizens, to obtain economically lucrative jobs outside of their local communities, and to cope and adjust to new information as the world evolves [126]. Proponents for word teaching methods argue that individuals do not identify individual letters while reading, but perceive words as a whole because word processing occurs too fast to allow for processing every single letter [33]. However, more recent studies provide evidence that readers use a combination of methods, processing whole words along with syllable sounds and letter groups in parallel [181]. While these different methods have their merits, deciding on a method to use while deploying an educational intervention might be language and location dependent.

In contrast to English, Swahili (the language of primary school instruction in Tanzania) is a highly phonetic language (there is a high grapheme-to-phoneme and phoneme-to-grapheme correspondence), therefore may be more suitable for teaching reading with syllables as the unit of words. Even within same-language contexts, studies have found different results with different approaches. A study comparing 5-7 year-olds living in English-speaking countries found that children in England (taught using letter sounds) and the United States (taught using letter names) performed similarly on standardized spelling tests, yet English children produced more phonologically plausible spellings for nonwords [58]. Our learning system teaches children to read in Swahili using both a letter and a syllable reading approach using games, songs, storybooks, and rote practice of reading units with automatic speech recognition.

Handwriting training is also a very important component of any well-rounded early childhood literacy intervention regardless of the platform it is deployed on. It improves fine motor skills and stimulates areas of the brain that control self-regulation and executive function [51]. Children who are learning to write, especially copying characters, must self-regulate, demonstrate impulse control and attentional flexibility, as well as utilize working memory [53]. Teaching handwriting skills (including tracing and copying letters) in early literacy education has been associated with better academic performance in different domain areas including math and reading among K-1 students [82,109,182]. When children's writing skills are developed before they begin formal schooling, there is an associated increase in overall academic achievement through second grade. Our learning system teaches children to write letters, numbers, and words with different levels of scaffolding and automatic handwriting recognition to provide performance feedback.

2.1.2 Student Support in Different Learning Environments

Adult Support in Learning Environments

Teacher quality is one of the most critical determinants of student success [46]. Teachers serve as experts, central and authority figures in the classroom, fulfill the role of an architect that designs instruction in such a way that meets the unique needs of the students [102], and equip students with tools that help them reach higher communicative and intellectual goals [207]. In addition to the expectations for providing guidance in learning, teachers communicate their expectations to students for behaviors they value in the classroom, either through positive reinforcement or through sanctions when those expectations are violated [148]. These expectations convey to students the degree to which their learning behaviors such as collaboration, class participation, and self-guided learning are permitted or expected. Such expectations are, much like peer learning behaviors, often culturally determined [213].

Parents similarly communicate their expectations for their children's behavior in more or less explicit ways, though they may not necessarily take on an explicitly instructional role as teachers do [212]. Various aspects of "parenting style" may contribute to communicating expectations for children's appropriate behavior, from consistent enforcement of rules, to varying provision of structure for children's activities, permitting more autonomy and exploration from children, and provision of warmth, nurturance, or approval to their children [213]. All of these parenting approaches contribute to influencing children's behaviors in the home, learning-focused or otherwise, and all of these are, as with teachers', socio-culturally constructed and influenced (see sections 2.2.4 and 2.2.5 for teaching practices and cultural norms that may influence children's behaviors in Tanzania specifically).

Peer Support and tutoring in Learning Environments

It is widely accepted in the learning sciences community that collaborative peer learning is beneficial for student learning outcomes. Collaborative learning is defined as "an instructional strategy in which students work actively and purposefully in small groups to enhance both their own and their teammates' learning" [1,156]. Studies show that students learn more effectively when they learn in groups rather than working alone [45,178]. Peers engage in instructional discourse that can bring about positive learning gains, including "modelling, assisting, directing, tutoring, negotiating, affirming, and contradicting each other", among others [186]. They engage in a variety of activities including lecturing, providing and evaluating answers, offering advice and problem solving strategies, and motivating their peers [34]. However, studies also show that not all students are equally as likely to provide high-quality instructional discourse [11]. Prior research suggests that the quality of collaborative discourse is highly dependent on individual factors such as students' prior knowledge and self-efficacy, as well as their relationship to one another [143].

Peer interactions should not be limited to pre-assigned tutor/tutee pairs – as long as students are grouped according to similar age and skills, they can provide mutual support for one another with adequate structure [94]. Allowing children of similar age/skills the opportunity to support one another without pre-assigned roles promotes a more equitable model of help-seeking and help-giving. Across different cultures, high academic achievement is positively associated with peer acceptance [37], therefore, pre-designating some students to only receive help might have negative effects on their social status and interaction with their peers.

The support that students offer one another becomes even more important when educational technologies are deployed in unsupervised settings, where children must rely on each other to navigate and learn from such systems. Some research studies have reported positive outcomes from unsupervised settings, reporting an increase in student curiosity [123], and even marginal learning gains [28], but do not provide any insights on the social interactions that lead to such outcomes. For instance, Kumar et al. provide rich insights from conducting an unsupervised learning research study using a mobile phone in rural parts of India [99]. They found that beyond infrastructural issues such as inconsistent electricity, factors such as gender, caste, and time of day significantly affected student interactions with the learning content. The authors report that children learned to support their peers from watching the experimenters navigate the devices, but provide few details on how this knowledge transfer occurred. As Pea, among others have pointed out, while intelligence may be distributed among children learning together and the tools they use to learn, such learning can benefit from guidance and structure from adults as well as from the intentional design of learning technologies to support collaborative behaviors [147,148].

Part 2 - The Influence of Culture on Learning and Teaching Practice

2.2.1 Understanding cultural group membership

Cultural groups are a coherent and stable ensemble of individuals to which a culture can be associated [24]. Many definitions for culture have been proposed, which come from a variety of traditions and are often strongly influenced by the interests of a particular discipline. Some domains, such as archaeology or anthropology, heavily consider cultural artifacts - highly relevant when designing a virtual cultural environment or including concrete examples as pedagogical resources. In cross-cultural psychology, Kashima [89] describes the existence of two main schools of thought that drive behavioral and cognitive conceptions of culture. The first, *system-based* theories, define culture as "a relatively stable system of shared meanings, a repository of meaningful symbols, which provides structure to experience" [see e.g., 76,80,196]. These theories tend to focus on comparisons between culturally specific dimensions of human nature, while separating out what is "universal", and have a relatively long-term view of cultural change. The second, *practice-based* theories, take culture to be constituted of "a process of production and reproduction of meanings in particular actors' concrete practices … in particular contexts in time and space" [see e.g., 41,163]. These theories take a more short-term view of cultural production and change and examine how culturally-bound practices are taken up and distributed.

2.2.2 Defining the Characteristics of Different Cultural Groups

One of the most popular approaches to defining characteristics of different cultural groups is a *System of values* framework that consists of identifying universal dimensions of the major orientations of cultural groups so as to develop group-specific models, thus providing an easy method for cross-cultural comparisons and assessments, and for potentially explaining cultural specifics. Universalisms are genuine characteristics of human beings supposedly shared by a wide cluster of (if not all) cultural groups. Group specifics are characteristics peculiar to cultural groups in that they are understood or endorsed by an important portion of insiders and unknown or considered external by outsiders. At present, the most popular system of values results from the analysis of a large-scale cross-national survey from a tradition of Education and Organization Management. Between 1968 and 1972, Hofstede surveyed more than 100,000 employees of the IBM Cooperation in 72 different countries [77,78]. The cultural dimensions found were expanded to six dimensions by 2011 and represent one scientific basis of people's understanding and interpretation of cultural differences.

Hofstede's framework computes numeric scores for a country along the following five dimensions: a) power distance (PDI: "*the extent to which the less powerful members of organizations and institutions (like the family) accept and expect that power is distributed unequally*"), b) individualism/collectivism (IDV: *the degree to which individuals feel indebted to themselves vs the group as a whole*), c) masculinity/femininity (MAS: "*the distribution of roles between the genders*", and a preference of competition vs harmony within groups), d) uncertainty avoidance (UAI: "*a society's tolerance for uncertainty and ambiguity*"), and e) long term orientation (LTO: referring to a general interest for "*virtue regardless of truth*"). Figure 2 presents scores of these dimensions comparing Tanzania to the United States. It is important to acknowledge that while Hofstede's dimensions may provide some assumptions about certain cultural dispositions, the insights gained from his sample of IBM employees, likely located in urban areas, may differ from that of student populations that live in rural areas.

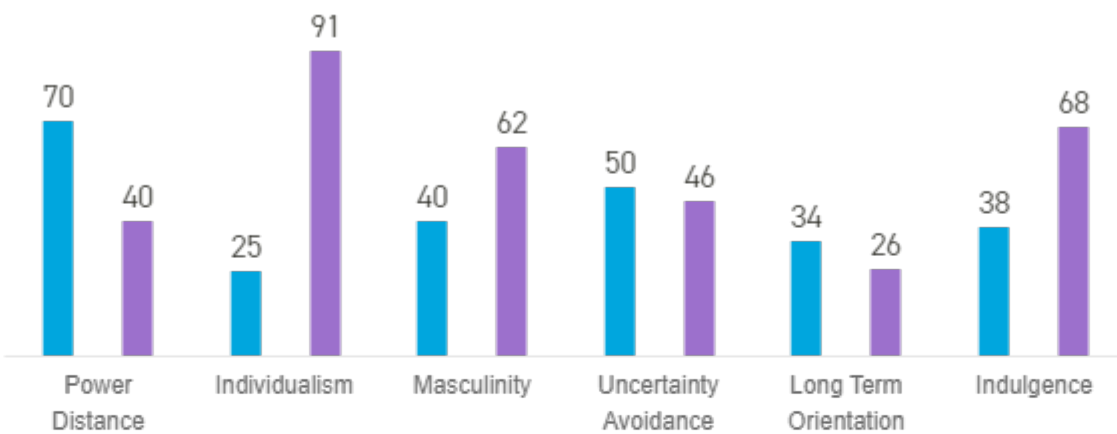

Figure 2: Hofstede's scores for Tanzania vs the United States; Blue is Tanzania, Purple is the United States

Based on Hofstede's dimensions, Tanzania has a much higher power distance compared to the United States, suggesting a classroom culture that is likely more authoritative, and teachers that feel the responsibility of owning and distributing knowledge rather than a space where knowledge is co-constructed between students and teachers. Tanzania also scores much lower on individualism suggesting that students may feel the cultural responsibility to care for and support one another. Finally, with a lower indulgence score compared to the United States, Tanzanian students may feel like their actions and behaviors are restricted by rules and social norms, and therefore be able to restrain themselves from providing support for their peers, even when there is the need to, due to the fear of being reprimanded. It is important to note that the Tanzanian educational system and norms are highly influenced by other cultures (such as being a British and German colony), therefore, their pedagogical ideologies may not be reflective of local help-seeking customs e.g. despite being a highly collaborative culture, the classroom culture may be predominantly individualistic.

2.2.3 Challenges with Rural Education in Tanzania

Access to education is considered a basic human right for every child in Tanzania. The government's efforts to increase student enrollment has seen much success (e.g. the number of enrolled secondary student increased by over 50% from 2008 to 2012 [189]). The government has also made directed efforts at improving classroom infrastructure, and teacher recruitment numbers by constructing staff houses [189]. Tanzania's educational system is structured as follows – 2 years to pre-primary, 7 years to primary, 6 years to secondary (broken up by 4+2 system of ordinary and advanced levels), and 3 years to higher education. Unfortunately, the growth rate of the number of available schools and teachers have not kept up with this increased education demand. In the same period between 2008 and 2012, the number of secondary schools only increased by 2.4%, and the number of teachers entering the system *decreased* by almost 10% from 2011 to 2012 [189]. Except for pre-primary, there are high stakes exams at each level that students must pass to advance to the next level of schooling [128]. This policy was instituted in 1995 but without specific guidelines on important factors such as teacher-student ratios, classroom sizes, or physical infrastructure. As expected, such loose guidelines disproportionately impacts schools in rural areas where classrooms often have no desks or even floor mats to sit on, and classroom sizes reach close to 100 children [127,128]. This places a higher burden on teachers to spend valuable time managing classroom dynamics and leaves little room for individual attention to students.

The issues with schooling in Tanzania are not only evident at the pre-primary level. Table 1 shows the 2010 enrollment statistics up to secondary school in Tanzania as reported by the Ministry of Education and Vocational Training [204].

Level	Male Students	Female Students
Pre-Primary (5-6 yrs)	461,628	463,837
Primary (7-13 yrs)	4,203,269 (+910%)	4,216,036 (+909%)
Ordinary Level Secondary (14 – 17 yrs)	177,176 (-96%)	149,639 (-97%)
Advanced Level Secondary (18-19 yrs)	20,381 (-89%)	13,299 (-92%)

Table 1: 2010 School Enrollment in Tanzania

Compared to the primary school enrollment numbers, there is limited participation at the pre-primary school level, and very high dropout rates at the secondary level. Studies report that these dropout rates are as a result of poor education quality especially in rural areas, high stakes exams, far distances to schools, and the physical remoteness of rural schools which makes it challenging to monitor teacher progress [130]. Also, there are challenges on the demand for education – the opportunity cost for parents to enroll their children in school rather than engage in other short-term economically productive activities is high [107], the rigid schedule of formal schooling does not take agricultural harvest seasons into account, and the perceived lack of alignment between school content and local contexts reinforce ideas that school was created for those from a different culture [191]. Even when rural parents place a high value on schooling, their own lack of education often limits their ability, sometimes resulting in embarrassment, in discussing academic topics with their children [191]. Unfortunately, these trends have not improved over the years – reports show that the number of out-of-school children in Tanzania had almost doubled in 2017, and that while pre-primary registration numbers are increasing, enrollment in other levels of education have been decreasing over the years[6].

Finally, Tanzania faces major challenges with recruiting teachers to work in rural schools. Lack of adequate transportation facilities makes everyday activities such as getting to schools, doctor and family visits,

[6] http://uis.unesco.org/country/TZ

collecting their salaries etc. very difficult for teachers [130]. A survey conducted in 1995 showed that about 38% of teachers in rural areas of Tanzania were absent for two or more days in the previous week [97]. These numbers may have improved slightly over the years – a more recent study conducted in 2013 showed that about an average of 24% of Tanzanian teachers (in rural and urban areas) were absent at the time of an administered survey [224]. Also, the quality of housing in rural areas, working conditions, and unavailability of leisure activities is equally discouraging to teachers [16,17]. These problems are exacerbated by the diversity of languages spoken in Tanzania – families from rural areas often speak only the local language that a teacher from another part of the country is unable to understand, posing a communication barrier while teaching [130]. Despite the relatively high numbers of women who enroll in teacher training colleges, they are often unwilling to teach in unfamiliar rural areas as it may pose safety concerns and limit the marriage potential of single women.

To alleviate some of these issues, countries such as Lesotho, Mozambique and nearby Uganda offer attractive monetary incentives to teachers who elect to teach in rural areas. The Tanzanian government has no such policy on a national scale [130], but specific regions in Tanzania have instituted incentives (such as set salaries, bicycles for transportation, beds and mattresses, and even kitchen utensils) to attract teachers to their regions [189]. However, studies conducted in other African countries suggest that these incentives make very little impact on addressing teachers' willingness to work in rural areas. One study in Zambia showed that there were no significant increases in workers retention in the ministry of education despite offering them both financial and non-financial incentives [113]. Also, another research study examined how Ghana attempted to address the teacher shortage issues in rural areas. Despite the government efforts to directly sponsor teacher education in exchange for teaching in rural areas, teachers tended to leave for urban cities after the mandatory working years were complete [39]. All these factors, along with the limited opportunity for professional development for teachers in rural areas, increase the educational disparities in Tanzanian rural areas, and make education technologies an attractive solution (as it by passes most of these issues), however may introduce other issues such as maintaining existing cultural norms for teaching and learning.

2.2.4 Teaching practices in Tanzania

The classroom is an organized system of social interactions with institutional and socio-cultural norms influencing students and teachers behaviors [3]. These norms influence help-seeking and help-giving behaviors and may affect the efficacy of educational interventions if unaccounted for. For example, in certain contexts, teachers encourage children to collaborate freely with one another [70], while in others (such as some areas of Tanzania), help-seeking collaboration in the presence of a teacher is uncommon. While teachers primary responsibility is to disseminate and facilitate learning in the classrooms, encompassing all the attributes of an effective teacher is the "knowledge, understanding, acceptance, and sensitivity to cultural and human diversity" [36]. Cultural norms can profoundly influence teaching practices [149,159]. Research studies show that "teachers develop culturally shared ideas about what good teaching and learning look like even before they begin their teaching careers" [44], and that students who are training to become teachers already have preconceived notions about what good teaching practices are [217]. In high power distance countries (such as in Tanzania) for example, the teacher is likely sole authority in the classroom, students are not generally expected to speak until they have achieved mastery of the material, and teachers are generally expected to have all the answers to students' questions [21,22,48,103,152]. Therefore, creating learning environments where students are expected to naturally take on leadership roles and help their peers may be more difficult in challenging in traditional learning contexts e.g. the classroom despite the benefits it may bring.

Researchers such as [128,185] have provided valuable insights on the teaching culture in Tanzanian classrooms. They report that communication is primarily teacher-dominated, and even when more time is allowed for lectures, the teachers generally talk for longer rather than incorporating collaborative practices such as group work. Students generally speak up only when called upon or instructed to do so, or to report conflicts with other students; when they initiated conversations unprompted, the teachers either ignored or silenced them. Stambach (1994) aptly names her paper based on a direct quote from a teacher, “Here in Africa, We Teach; Students Listen”, to underscore this teaching culture, although she emphasizes that this teacher dominance does not necessarily translate to students staying quiet in the classroom. Research studies have found that loudly reciting learning facts, singing, and dancing are routine parts of the lecture in Tanzanian rural classrooms [198]. As the classroom sizes increase, this teacher dominance also increases as it becomes impractical to effectively facilitate collaborative activities among the children. Mtahabwa et al. (2010) also found that teachers management styles have a profound effect on the atmosphere of the classroom. They found that teachers who are less qualified (highly prevalent in rural areas) made excessive use of threats, rules, and disciplinary action to manage their classrooms compared to their urban counterparts, resulting in even quieter and lesser active students. The expectation of disciplinary action by classroom teachers may also be reinforced by parents who want their children to learn to uphold certain behavioral standards while learning in the classroom.

Creating education technologies that potentially violate these teaching norms may not have positive effects on student learning in a classroom environment. However, the challenges with providing high quality education and recruiting teachers in Tanzanian rural areas calls for interventions that foster students’ support for one another, as a knowledgeable adult may not be available. The potential unavailability of knowledgeable adults make it important to develop learning technologies that can support students in unassisted learning environments, but also calls for an investigation of the effects of such interventions on students’ behavior in the classroom if they have to navigate both traditional teacher-led, and unassisted learning spaces.

2.2.5 Cultural Factors that Influence Help-Seeking and Help-Giving Behaviors

Cultural preferences dictate how people demonstrate their mastery of knowledge; ignoring these preferences can cause undue stress and demotivate students. One example is the use of frequent and mandatory testing to assess the knowledge gained by students in the classroom. While this practice is acceptable and effective in certain cultures, it is a foreign concept in others e.g. in American Indian and Alaskan Native cultures [49]. Another educational practice whose success is dependent on culture is questioning students directly in front of their peers. The practice poses a challenge to students whose culture only allows people to speak only when they feel prepared to do so. It implicitly causes students to compete with each other which may be frowned upon by certain cultures [50,151].

Directly related to student interactions, the debate style of discourse in Western education may be uncomfortable for students from cultures with high power distance, and those that value group harmony over asserting one’s individuality (such as in Tanzania). Students from Western cultures generally take a more active role in their learning through participating and questioning the teachers, even without mastery of the subject, while students from other high power distance cultures may prefer passively receiving instruction and avoid participation until they have achieved mastery [220]. The desire to promote harmony may cause students from collectivist discomfort when forced to express their opinions – students may also apprehensive of making mistakes or making others feel uncomfortable [40,194,195,197].

Other factors such as culturally ascribed gender roles, and group dynamics may affect classroom culture. Cultural norms can profoundly influence gender roles [69,87,177]. In some cultures, males have more influence in group discussions, and have a greater chance of being elected group leader [152]. Teaching practices that disturb these accepted patterns of student interactions (such as promoting peer-peer help-seeking) may be detrimental to the students' psychological wellbeing. In Tanzania specifically, research studies suggest that there are clearly ascribed differences in the expectations and responsibilities that girls are given compared to boys. Meena et al. [116] report that girls have additional responsibilities in the home limiting their time for homework, and that subjects taught in schools emphasize themes that make girls subordinate to boys. Even in pretend play, children self-select to participate in activities that are in alignment with existing, culturally dictated, gender norms [20]. Girls are often not allowed to play competitive sports, which reduces their willingness to compete with their peers and speak up for themselves.

Despite these challenges, the everyday living practices of Tanzanians are more reflective of a culture where help-giving and collaboration is the norm. Nalkur et al. [132] report that even homeless children in Tanzania, with their extremely limited resources, feel an overwhelming sense of responsibility towards other homeless children. A qualitative study by Evans [59] reports that in Tanzanian households, older siblings generally have the responsibility of instructing, guiding, looking after, making money, and doing homework with their younger siblings to free up their parents for other income earning and family care activities. It is common practice for neighbors and friends to help children cook and care for their sick siblings to allow them go to school [104]. Neighbors even give children the opportunity to earn money for their school fees in exchange for doing domestic tasks. [132]. Children (especially girls) often give in to the pressure that this care taking responsibility brings upon them, dropping out of school to focus on caring for their siblings. Since help-seeking and help-giving are so prevalent in this culture, educational technologies designed to foster such behaviors may especially thrive (if they are deployed in the absence of authority figures such as teachers) as it allows students to engage in behaviors that they routinely engage in outside school contexts.

Part 3 – Educational Technologies to Support Equitable Help-Seeking in Learning Systems

2.3.1 Educational Technology Interventions in Rural Contexts

The rising number of out-of-school children all over the world has led several organizations to attempt to tackle the issue using interventions that scale much faster than traditional schooling. The affordability, scalability, and ubiquity of mobile devices in developing regions have made them a popular solution in the attempt to close the academic proficiency gaps between urban and rural students. Technologies that have shown potential to produce learning gains include traditional desktop computers [122], tablets [28,199], and even feature phones using interactive voice response technologies [112]. There have been several initiatives conducted in African regions specifically – some directed at augmenting inadequate traditional schooling, while others focus on supporting out-of-school students. The One Laptop Per Child (OLPC) program provided primary school students from several African countries e.g., Tanzania, Ghana etc. with individual low-cost laptops to support their learning in school. Unfortunately, most of its success was hindered by the lack of infrastructure, support staff, and adequate security for the devices. In Tanzania specifically, research studies show that parents and teachers of secondary school students perceive mobile phones as a distraction for students even when pre-loaded with educational content [92].

For out-of-school children, Breazeal et al. deployed a tablet-based educational application in two villages in Ethiopia, and found that even in out-of-school contexts, over half learned more than 50% of the vocabulary provided [28]. Furthermore, our research team has worked with rural communities in Tanzania over the last three years, reporting on how children interact with tablet-based education systems in both home and school settings, and providing insights on the types of struggles children face in the learning process [199].

Recently, the Global X-Prize Learning initiative partnered with UNESCO and launched a competition challenging educators and technology developers to create an early literacy system to be deployed in English and Swahili to out-of-school children in rural areas of Africa [64]. Five different tablet-based early literacy systems (including the system described in Chapter 3) were deployed in Swahili to over 2500 children spread over 141 rural villages in Tanzania. Prior to the competition, over 90% of the students could not read a single word in Swahili. At the end of the 15-month trial, over 50% of the children had improved their reading skills using technology, and had become proficient in basic mathematics [65]. This initiative is the one of the largest scale trial of its kind, evaluating the possibility of technology alleviating this global crisis, and is evidence that with proper design, children in rural contexts in Tanzania can improve their literacy and basic math skills outside of the confines of the formal schooling system.

2.3.2 Help-Seeking in Intelligent Systems

Prior to the increased focus on system-supported help interactions, human tutors were always considered ideal for supporting students learning needs. Human one-on-one tutoring is very effective, producing two standard deviation increases in learning gains [26]. However, human tutors are expensive and cannot scale in environments where millions of children need support. Another model of providing student support involves hiring one tutor who is responsible for supporting many students, relying on students to request help from them as needed. However, is model is potentially problematic especially in contexts similar to our target demographic. Research studies suggest that there are two main kinds of help-related errors that students make in a learning environment (technology-driven or otherwise). Students either avoid seeking much needed help altogether, or utilize help resources excessively which prevents them from learning effectively [7,88,165]. This issue is especially detrimental to students who need the most help as they often exhibit the poorest help-seeking behaviors [88,160,218]. These findings are not surprising as the recognition of one's need for help, and requesting it at the appropriate time, is a complex meta-cognitive skill that requires students ability to monitor their own progress and understanding [5,203]. Therefore, relying on students who have never consciously taken up the responsibility of constructing their own knowledge to possess these metacognitive skills, and request for help from a tutor assigned to many students is risky. For early learners such as our participants in rural Tanzania, this one tutor to many students' model is unlikely to be effective.

To address the need for more scalable tutoring solutions, interactive systems equipped with advanced knowledge tracing and tutoring algorithms have been developed, and are proven to be effective in several controlled studies for increasing student learning in and out of classrooms [96,202]. Some of these interactive systems monitor student interactions and learning progress, and provides adequate support as necessary, rather than rely on students to recognize their own errors and request help accordingly. Therefore, in contexts such as our target rural communities in Tanzania, providing learning systems with intelligent monitoring, tutoring, and help-seeking capabilities is of paramount importance to maximize student learning gains.

For interactive systems to be effective in specific cultural contexts however, they have to be developed by or with people who are aware of the teaching and learning norms of the target demographic. Without human support, interactive systems may not sufficiently meet students' needs especially if designed by educators and developers who are unaware of the target culture and familiar teaching/learning practices. Most of the educational interventions (discussed in section 2.3.1) are initiated by educators who are not part of the local culture, who need to design solutions to maximize student learning. Since knowledgeable adults are not guaranteed in rural low-resource contexts, taking advantage of available peers to provide human support in areas where interactive systems are ill-equipped seems to be a viable option. Given that experts from these target populations are often inaccessible, a system that scaffolds student interactions to utilize local resources e.g. their peers, along with error and performance monitoring can potentially be most effective for supporting students help-seeking needs.

2.3.3 Technology-Mediated Scaffolding for Peer-Peer Help-Seeking

To enable effective help-seeking behaviors between peers, researchers have employed different strategies to facilitate student interactions such as adults guiding student dialog [75], pre-collaboration training [155], or scripting student interactions by giving them pre-designated roles and actions to follow [60]. In the absence of knowledgeable adults, or in contexts where there are communication barriers, other researchers have incorporated features that foster help-seeking and collaboration among peers learning with education technology. In this approach, the software "serves as an additional communication partner, influencing communication directly [54].

To reduce anxiety related to help-seeking, Shung et al. [175] designed a technological intervention in a Hong Kong classroom, where students were allowed to stay anonymous when asking questions. This intervention allowed students to actively seek help from their teachers in an environment where they would not otherwise due their anxiety and need to save face in front of the teacher and their peers. Some other efforts have been directed towards improving collaboration in a other ways e.g. providing feedback on the quality of a solution submitted by a group of students [12], detecting problem relevant topics in student dialog and engaging them in tutorials around those topics [100], and tracking student actions to provide feedback on the correctness of the answers that tutors provide to tutees [54]. Other technology-driven initiatives provide collaborative spaces such as chat rooms, allowing students to work on math problems in a shared workspace and discuss appropriately [184]. All these interventions have had positive effects on improving student interactions. Unfortunately, several of them are not feasible for rural contexts with limited resources e.g. interventions that require an internet connection.

Results from my prior work in Tanzania show that in addition to receiving timely help, students want to maintain the agency of electing to request for help when they want, and providing them with unrequested (even when needed) help may be negative to their overall learning experience [198]. Therefore, a solution that facilitates peer to peer learning, runs completely offline, and allows students the opportunity to request for help from their peers seem most promising for this socio-cultural context. While students can choose to, or be offered the opportunity to seek for help when they please, the constant error monitoring done by the system ensures that students are directed to peers who actually have the ability to give them the support they need.

2.3.4 Feedback systems

When interactive systems are designed to support student learning, the timing of providing feedback is very important. Determining when and how to provide feedback and support for students while learning with education technology is a topic that has gotten a lot of attention in the learning sciences research community. Some researchers such as [42,105] are proponents for providing feedback and scaffolding immediately errors occur, citing that it allows students to practice generative skills. Lewis et al. [105] conducted an experimental study where they either gave students immediate or delayed feedback in a maze-based adventure game. They found that students who received immediate feedback provided more accurate answers for relevant operations when provided with the maze descriptions. More specifically related to an academic task, [42] compared the pedagogical benefits of providing students with immediate vs delayed feedback when learning with a math intelligent tutor. They found that there were no significant performance differences in both feedback conditions, but students in the immediate feedback condition completed the activities much faster, minimizing unproductive floundering.

Other researchers such as [62,120] maintain that human tutors do not give immediate feedback to struggling students, and cite research studies that students who are discouraged from requesting unnecessary help, and allowed to engage in productive struggle, score higher in later post-tests. They argue that giving students immediate help when learning with interactive systems causes them to depend unnecessarily on feedback and prevents the practice of evaluative skills such as monitoring their own understanding and correcting their errors – skills that are relevant for long-term information retention. Lee et al. [101] conducted an experimental study varying the timing of feedback students received while learning with a mathematics intelligent tutor. They found that although the students in the immediate feedback condition finished activities faster, students in the delayed feedback condition scored significantly better on a post-test administered days later. A similar study was conducted by [172], they found that students in the delayed feedback condition finished significantly faster and made half as many errors on a task assigned days later.

In an attempt to maximize the benefits of both feedback timing methods, researchers such as [114] focus on achieving a model of desired performance (intelligent novice model) rather than making the choice between immediate vs delayed feedback timing. Depending on the learning goals, a student can practice generative skills by receiving immediate feedback on certain tasks, and practice evaluate of skills by receiving delayed feedback on tasks that can benefit from productive struggle. This model assumes that even knowledgeable students, facing new kinds of problems, encounter errors but do not necessarily need to receive help to recover. Error detection and activity monitoring is a critical part of such a system to ensure that students receive the right kind of help, at the right time, and prevents unproductive struggling.

To evaluate the efficacy of this model, [114] deployed a spreadsheet tutor based on the intelligent novice model, allowing students to make mistakes (e.g. enter wrong formulas), experience the consequences of making those mistakes, and the opportunity to recover on their own. When students enter wrong answers and attempt to proceed to another problem, the system redirects them to check for errors, request hints etc. If students continue to struggle after a specified period of time, or fall below an acceptable level of performance, the system intervenes and proceeds to walk them through a solution. Students in the intelligent novice model condition outperformed students in all the other conditions on isomorphic tests, transfer tasks, tests of conceptual understanding, and a retention test administered eight days post training.

My help-seeking system is built based on the Intelligent Novice Model. A system based on the Intelligent Novice Model helps to maintain a desired model of student performance by incorporating error detection and correction as part of a task, providing some immediate instructional scaffolding throughout an activity, and providing delayed feedback with additional help to allow students time to recover from errors by themselves. Given the digital literacy of our target students, our system shows students videos on how to navigate every activity type to circumvent application navigation errors. In addition to providing multiple levels of scaffolding on individual tasks, the system constantly monitors student errors and activity performance to provide help-seeking suggestions after students have the chance to engage in some productive struggle on their own. The system detects the most frequent kinds of errors that students encounter (discussed in chapters 4 and 5), allows them to struggle for a given amount of time (calculated based on average task completion times and the maximum number of attempts per task), and intervenes by alerting them to the presence of a helper button which redirects them to seek for help from a specific student. Our feedback system never interrupts student game play, rather, it alerts students of the opportunity to request for help while struggling, giving them agency to either accept the help suggestion or ignore it and continue to receive support using the normal activity scaffolding.

Chapter 3 - Learning Application

The learning application used in all of the research studies reported in this proposal is focused on the following learning areas, deployed in Swahili: literacy (letter and phonemic awareness, writing, stories curated from the African Storybook Project - http://www.africanstorybook.org/), and math (number identification, number writing, addition and subtraction). Most system interactions involve tapping on the screen, although some require tracing, writing, or speaking to engage, with a speech recognition engine validated in various African contexts [122], and video tutorials with continuous finger placement scaffolds to support children's' digital literacy . The Swahili audio prompts, and instruction were recorded by a Kenyan Professor of Swahili, who has taught Swahili from kindergarten to university levels. The Swahili video application tutorials were recorded by a Tanzanian instructor of Swahili, who grew up in a region about 10 hours away from the village where the study was conducted. All communications with the children were translated by a native Swahili speaker who lived in the same village and was well-known to the children. More details about the learning application can be found in [199].

The learning application was designed to cover the following topics in literacy and math:

Math:

- Identifying, reading and writing single, double, and triple digit numbers
- Number discrimination and missing number patterns
- Addition and subtraction of numbers up to 1000

Literacy:

- Recognizing, reading, and writing letters, syllables, nonsense words and 2nd grade equivalent words.

3.1 Learning Application Design Motivations

Research studies show that there are negative outcomes when curricula do not match the values of the learners. These trends are observable in cultures that have the liberty of setting their curricula (Confucian, Islamic), as well as cultures where they might not have control over their current curriculum as a result of factors such as colonization, and the presence of other dominant cultures [140]. Cultural values and practices have been directly linked to e.g., the ways that students prefer to be taught, how receptive they are to the instructor, assertiveness, how they seek out challenges, and how they manage their time [35,84]. Studies show that students perform better when learning with curricula grounded in their culture [23]. Making schooling and education relevant to students' culture increases their self-esteem, their identity formation, their political activism, and their community participation [86]. It helps to mitigate the negative experiences they have with learning, supporting resilience. Culturally-relevant education has also been shown to directly improve student outcomes including grades, school attendance, timely assignment completions, and post-secondary ambitions [86,106,131,221]. Studies investigating the effects and process of making an educational system culturally aware include [15,18,31,32,68,86,90,133,161,173,180,188].

As a result of these findings, we designed our learning system with our end users in mind. In [198], we collected and analyzed data from 16 classroom observations sessions in rural villages in Tanzania sessions (8 from a public school; 8 from a private school), including handwritten observations and photographs of the school and classroom artifacts. Next, we identified emergent themes related to recognition, reading, and writing instruction following a grounded theory approach. Four themes of instructional pedagogy emerged: 1) the central role of music for all kinds of instruction, 2) situating learning using real-word pictures and familiar contexts, 3) regular use of rote repetition to support knowledge retrieval, and 4) emphasis on syllables (rather than letters) as the unit of reading. As a result, we made the following changes to our learning system:

- We added two types of songs to our reading tablet application to increase student engagement: songs covering specific domain content (e.g., numbers and letters) illustrated with the text of the content, and other songs, similar to nursery rhymes, illustrated with pictures and the text of the songs. All songs were recorded, and all pictures were vetted by a native Swahili speaker born and raised in Tanzania to ensure accurate translation and that the objects matched students' experience (e.g., toilets look very different between urban and rural Tanzanian regions).

- We incorporated several word reading activities with familiar words, including animals, common village objects, family, food, etc. Each activity was accompanied by a relevant photograph (either sourced from an open source image library or created specifically for the application), as well as the text for the target word. Children had opportunities to practice the same words without the accompanying pictures in harder activities.

- The PARROT mode of our reading application is most similar to rote repetition, and the ECHO/REVEAL/READ modes are most similar to in class activities where the teacher highlights an item on the chalkboard and elicits student response. While these methods had varying levels of engagement in the classroom, deploying them one-on-one with students may provide more insights about how to make such a teaching approach more engaging.

- We included modules in our reading and writing applications to introduce students to vowels and their sounds, then briefly to all letters, and finally teaching them to read and write syllables prior to introducing them to words.

Our results showed that pedagogical techniques that are engaging in the classroom are potentially also engaging on tablet-based education activities even for children without formal schooling or adequate digital literacy. Given that the logistics of observing and co-creating applications with our target population may be particularly challenging due to access, we showed that observing a much smaller set of classrooms can produce insights that increase the engagement of applications on a much larger scale. By using our reading and writing applications for only 6 sessions a month, students demonstrated statistically significant growth in their reading and writing scores compared to non-culturally adapted content.

Of the pedagogical techniques observed, music was highly engaging in the classroom, as well as on the tablet-based application. This was expected given the high value placed on music as a teaching tool in this cultural context, as well as the plethora of academic, psychological, and cognitive benefits that music brings to learning [67,121]. Providing the students with syllable-based activities to support their reading proved to be highly engaging. Although we were not surprised by observing this teaching method given the phonetic nature of Swahili, we were surprised that these effects were evident even with children who have no formal schooling. Relying on word familiarity to increase student engagement only showed positive results with the writing application. The Inverted-U hypothesis, which stipulates that people will often prefer activities that are marginally more difficult than their comfort zone, may explain this effect [108]. Word familiarity may have caused boredom and therefore less engagement with rote-repetition activities but was enough of a motivational boost to help them persist through the writing activities. Although the value of teaching using rote repetition is debated within the learning science community [190], there are some documented benefits including improved recall ability, as well as introducing students to foundational knowledge [225]. Further research is required to explore other ways to make this activity more engaging.

3.2 Applications within the Robotutor Learning System

The following are the learning applications in our system:

Bubble Pop: This application enables the recognition of letters, numbers, words and syllables. Students either see and hear a target answer to test their ability to match a target to the stimulus, or they only hear the stimulus testing their ability to recognize a target based on its sound. This tutor is also used to implement a missing number activity, and a number comparison activity with appropriate audio prompts. To answer each question, students hear a prompt, and are required to tap the answer bubble.

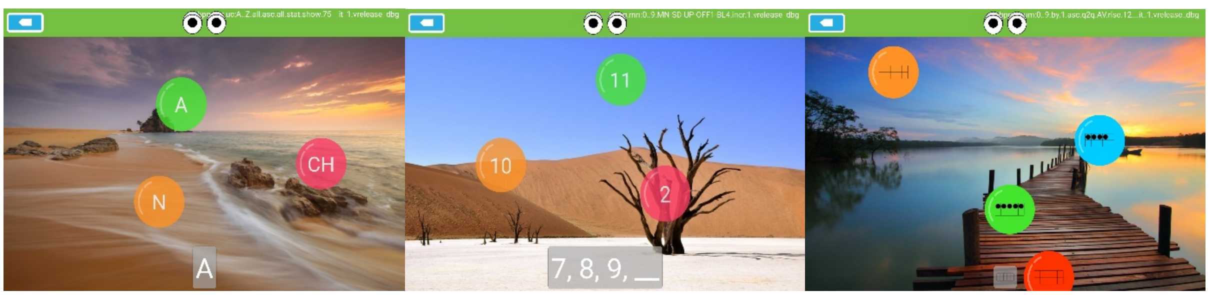

Figure 3: Bubble Pop Leaning Application

Akira: Similar to Bubble Pop, this application enables the recognition of letters, numbers, words and syllables using a car racing game metaphor. This application is more cognitively challenging even for equivalent activities in Bubble Pop as students face time pressure to select the right answers to questions. To answer each question, students are required to move the car by tapping the lane that has the correct answer.

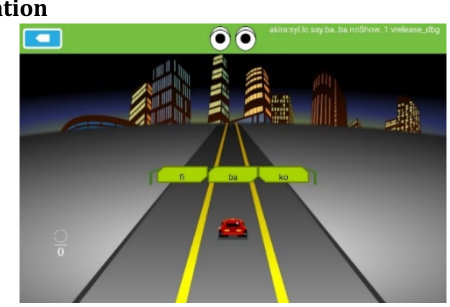

Figure 4: Akira Learning Application

Stories - Reading Application:

This application enables students to practice their reading skills by introducing them to age-appropriate words in the context of culturally relevant stories. The application recognizes speech input from students while providing pronunciation support and word highlighting to infer pronunciation correctness.

Figure 5: Story Reading Application

Character Writing Application:

This application allows students to practice their handwriting and improve their motor skills by teaching them to write on a learning tablet using their index finger. Students practice their handwriting throughout our learning system starting from tracing and writing individual characters, to writing words and writing responses to mathematical problems. Handwriting recognition is enabled in this application to provide correctness feedback.

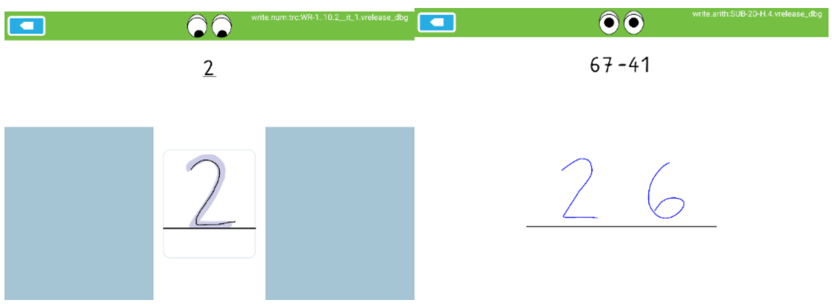

Figure 6: Character Writing Application

Picture Matching:

This application enables students to practice reading by encouraging them to associate familiar words and images with the written forms. Students are instructed to tap on the picture that matches the written word. If students tap on the wrong picture, the system plays the name of the picture they selected, telling them to try again without revealing the name of the target picture.

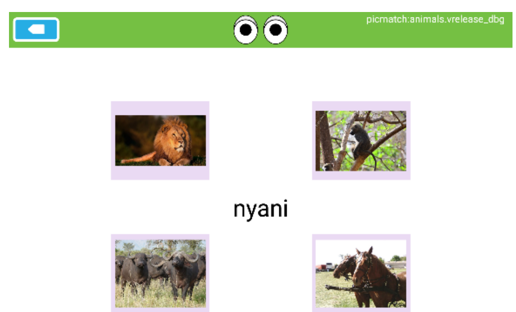

Figure 7: Picture Matching Application

Word Spelling:

This application encourages students to spell by sounding out familiar words and displaying familiar images, while giving them scrambled versions of the written form broken down by syllables. The system instructs the students to spell the word they hear/see by tapping on the syllable tiles in the correct order. For each tile students tap, they hear the syllable, followed by the target word in the activity.

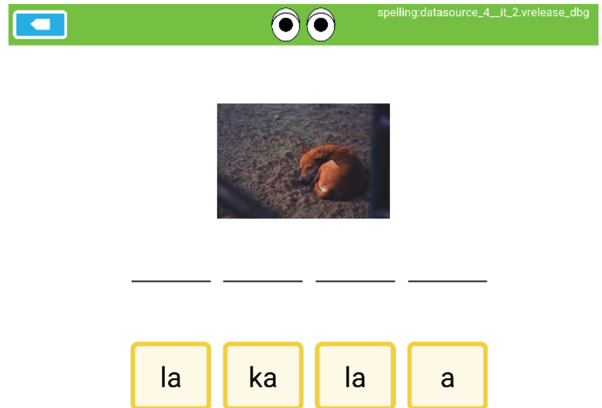

Figure 8: Word Spelling Application

Sentence Writing Application:

This application has similar input, feedback, and scaffolding as the character and word writing application. However, it teaches students to write sentences by teaching them about correct use of common punctuation, and word spacing in the construction of a sentence.

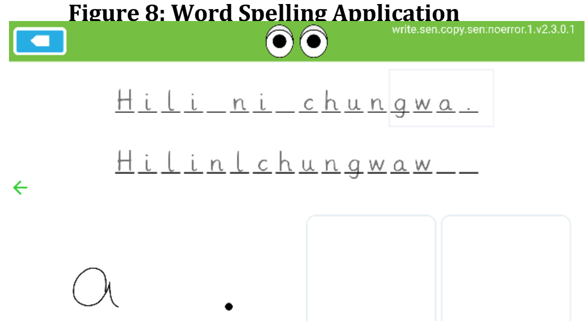

Figure 9: Sentence Writing Application

Number Discrimination:

This application teaches students number discrimination and counting, by displaying two numbers and asking students to tap on the larger or smaller number. To support learning, students are provided with the quantity equivalent of each numeral.

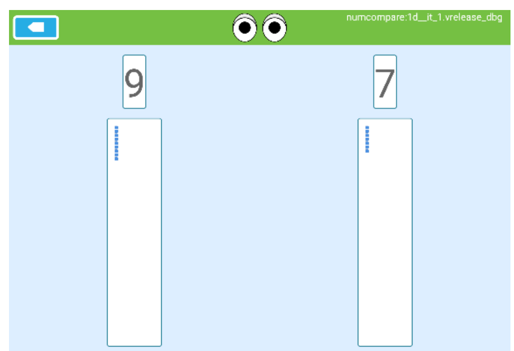

Figure 10: Number Discrimination Application

Big Math:

This application teaches students to add and subtract by providing interactive quantity equivalents of each numeral. The system recognizes student input using handwriting recognition for correctness feedback. Prior to this activity, students must have already mastered simple addition and subtraction of quantities, in the context of culturally appropriate word problems.

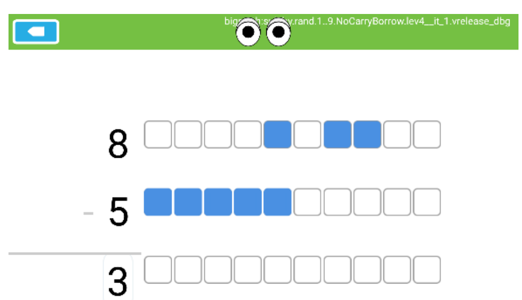

Figure 11: Big Math - Addition and Subtraction Application

Place Value:

This application teaches students place value by having them split a target number into its expanded form. The system uses the same representation for quantities throughout the entire system for consistency and knowledge transfer. Students also practice the addition of the expanded form of a target number by writing the individual numbers or the solution.

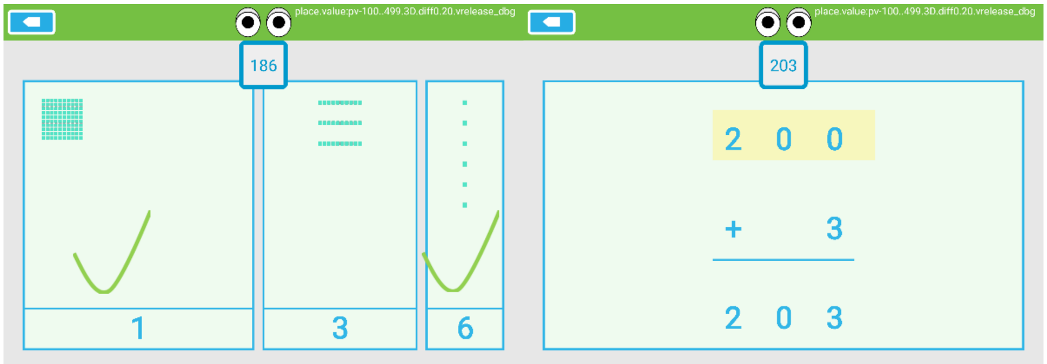

Figure 12: Place Value Application

Number Scale:

This application allows students to practice skip counting without the pressure of a graded activity. Students either tap the addition or subtraction buttons, and watch the number pattern increase or decrease as a result. This same number pattern formatting is used in the missing number activities as well.

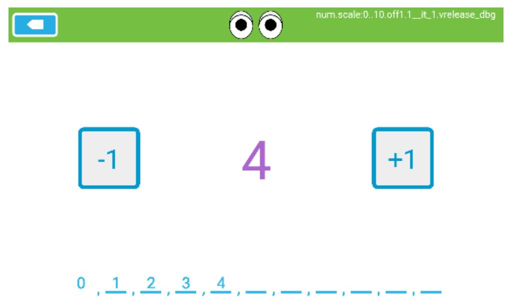

Figure 13: Number Scale Application

Counting X:

This is the first interactive activity that students encounter in our learning system. In addition to teaching students to count to ten, introducing them to numerals, and a 10-frame metaphor, this application is specifically designed for students with low digital literacy, who have never interacted with a smart device before. The target area is intentionally designed to cover the majority of the screen, with an object appearing anywhere a student touches with one finger. This is intended to teach students that they can interact with a screen by simply touching it with one finger after lots of trial and error. This activity is ungraded, and there is no student scaffolding provided to encourage productive struggle.

Figure 14: Counting X - Counting Practice Application

Listening Comprehension:

This application is similar to the reading application in that it uses the same kinds of word reading scaffolding. However, it teaches students listening comprehension by forcing them to respond to input by asking them specific questions like, "which word is likely to follow in this story?" or generic questions like "what do think about this story?". Students interact with this application by speaking out a response, or tapping an answer from a list of spoken options.

Figure 15: Listening Comprehension Applications - (L-R) Sentence Completion; Generic Questions; Cloze Questions

3.3 Promotion and placement Mechanism

The learning system is organized in a matrix table structure with columns. Each column represents a skill (e.g. identifying numbers from 1-10). The number of columns is the total number of skills in the learning system. Each column has many activities that make up a skill taught using several tutors. The items within a column are organized top to bottom from easiest to hardest. To assess student's current knowledge, every student is presented with the hardest activity starting from the first skill. If they score 90% or more, they are given the hardest item on the next skill. As long as they keep scoring 90% and above, they are promoted to the next skill. Once they score less than mastery on the hardest item, they are moved to the easiest activity in that column (skill).

After they are placed in a skill:

- If they score 90% or more, they are promoted to the next (harder) activity within the skill.

- If they score below chance, they are demoted to the previous activity on that skill.
- If they score better than chance but less than mastery, they are promoted or demoted to the next/previous activity within the column with 50/50 probability.
- If a student voluntarily backs out from an activity, they are promoted or demoted to the next/previous activity within the column with 50/50 probability.
- If a student scores more than 90% on the hardest item on a skill, they get promoted to the easiest item on the next skill.

3.4 Speech Recognition Application Features

Our Automatic Speech Recognizer (ASR) was adapted from a lightweight speech recognition engine, specifically tuned for handheld and mobile devices (PocketSphinx [81]). This tool has been used in prior research to enable speech recognition in mobile games for children in rural India [98]. It was modified for use as a Swahili ASR by including a Swahili pronunciation dictionary, and a pronunciation synthesis parser program, while maintaining the language model generator, the phoneme set, and an acoustic model used in a previously developed English ASR. Figure 16 shows a screenshot of a participant reading a story, with words highlighted to provide correctness feedback.

Students can tap on the current word (underlined), or the green audio button to hear the system pronounce the highlighted word. When the application detects a few seconds of silence, the instructions are repeated, followed by a finger hovering over the audio button to remind them where to tap for help. The current version of our reading application (including changes incorporated after the classroom observations) consists of the following modes:

- HEAR: Students listen to text (including letters, numbers, words, storybooks, and songs), without the need to provide a response.

- PARROT: This mode is identical to rote repetition. Students hear and see some text (sometimes with an accompanying picture) and are asked to repeat after the application.

- ECHO: This mode is the inverse of "parrot" mode above. Students are shown only text and are asked to read what they see. The application provides the correct pronunciation to the text on the screen after the student response regardless of correctness.

- REVEAL: Students are shown a picture and are instructed to say what they see. This mode is currently used to assess students' ability to say a number by looking at a picture of its numeral. The application provides the correct answer after the student response regardless of correctness.

- READ: Students are shown text and are asked to read what they see. Unlike the other modes, the application does not provide the correct pronunciation to each word – words are highlighted in different colors to provide correctness feedback.

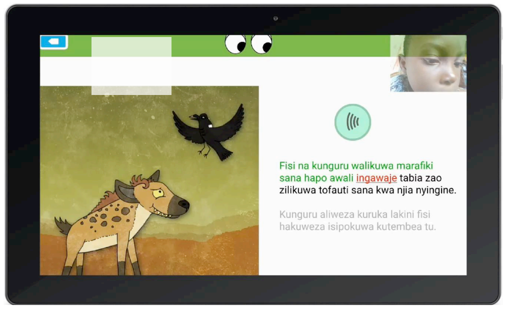

Figure 16: Screenshot of Pilot Student Reading a Story with Right/Wrong Feedback and Pronunciation Support Button

3.5 Handwriting Recognition Application Features

One of the most popular toolkits employed by handwriting recognition researchers, and mobile application developers is Lipi toolkit (http://lipitk.sourceforge.net) [223]. It allows for shape and word recognition, and individual character and string recognition. It has been used for developing handwriting applications on android mobile devices, and has been validated for use in recognizing handwriting of children, including those with dyslexia [91]. For our writing application, we modified this toolkit by adding features to score the similarity of the written character to the expected character and biasing it to prefer the expected character. Students provide input by writing on the screen using one finger.

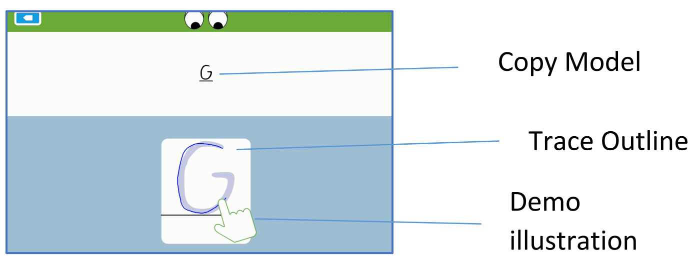

Figure 17: : Writing Application – TRACE mode includes copy model and trace outline; COPY mode includes only copy model; DICTATION includes only an audio button to replay target; all modes begin with a demo of the target activity.

Before each activity begins, students are shown a demo with a finger writing the response to an example problem (Figure 2). The current version of our writing application consists of these modes:

- TRACE: Students are shown an outline of a letter/syllable/number and are instructed to write over the outline. After three incorrect attempts at a given question, students are advanced to the next question.
- COPY: Students see the text to copy. Each subsequent attempt provides a repeat of the instructions or a temporary trace outline. By the fifth incorrect attempt, a trace outline remains in the writing box for scaffolding, and if a wrong response is still provided, students are advanced to the next question.

- DICTATION: Students hear a word without any text on the screen and are instructed to write what they hear. The scaffolding provided is similar to 'COPY' mode.

3.6 Student progress with our reading and writing applications

We deployed our system among 285 (1 tablet per child) children living in 5 rural villages in the Mara region of Tanzania. Of all the participants, 93% of the children could not identify a single two-letter syllable, and 96% could not read any primary-school level words or read a sentence. Unsurprisingly (based on their word and syllable scores), 98% could not correctly answer any reading comprehension questions, however, over 60% were able to answer at least 1 listening comprehension question correctly (with 11% providing correct responses to all questions). Overall, participants performed better in the basic numeracy questions topics to literacy. 41% of the children were able to identify at least one number correctly, 60% answered at least one question related to currency correctly, and 39% correctly answered at least one simple addition or subtraction word problem. On basic addition and subtraction problems, participants performed similarly to their literacy score. 86% could not solve a single basic addition problem with numbers and operators, and 89% scored 0 on similar level subtraction problems.

Figures 18 and 19 show the comparisons between student achievement levels at the beginning and end of the a 6-month trial with our system.

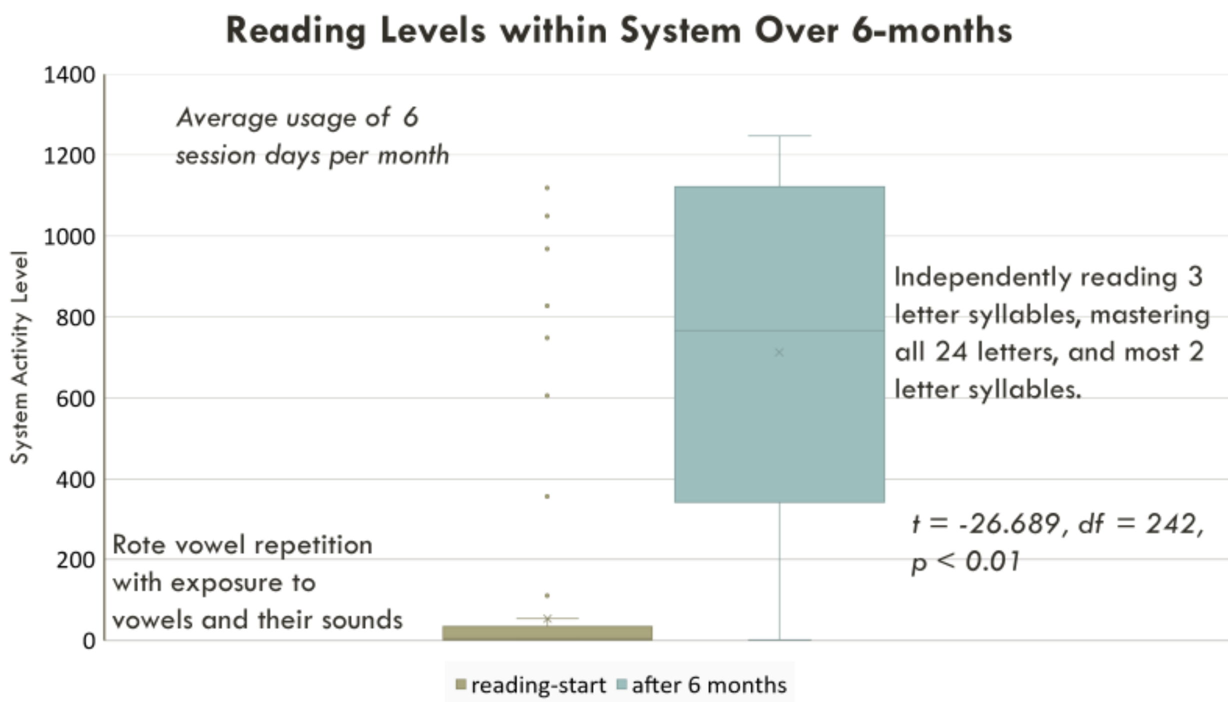

Figure 18:Students' reading levels before (median = level 5 – rote repetition vowels) vs after testing period (median = level 766 – reading of 3-letter syllables); Average use of 6 sessions per month.

Students' median beginning reading level was rote vowel repetition with exposure to vowels and their sounds. Figure 18 shows that 8 outlier students began at above-average levels. Based on the pretest scores, most students could not identify a single letter at the beginning of the study. At the end of the 6-

month period, with an average of 6 usage sessions per month, most students were independently reading 3 letter syllables, mastering all 24 letters, and most 2 letter syllables. This increase in student reading levels was statistically significant ($paired\ t - test: t = -26.689, df = 242, p < 0.01$).

For writing, the median beginning level was tracing the vowels. There were 6 outlier students who began at writing levels above the typical student. By the end of the 6-month testing period, with an average usage of 6 usage sessions per month, the median writing level was copying of 2-letter syllables. Students had mastered tracing, copying, and independently writing all numbers from 1-10 and all 24 letters. This difference in student writing levels was statistically significant (paired t-test: t = -20.533,df = 232,p< 0.01).

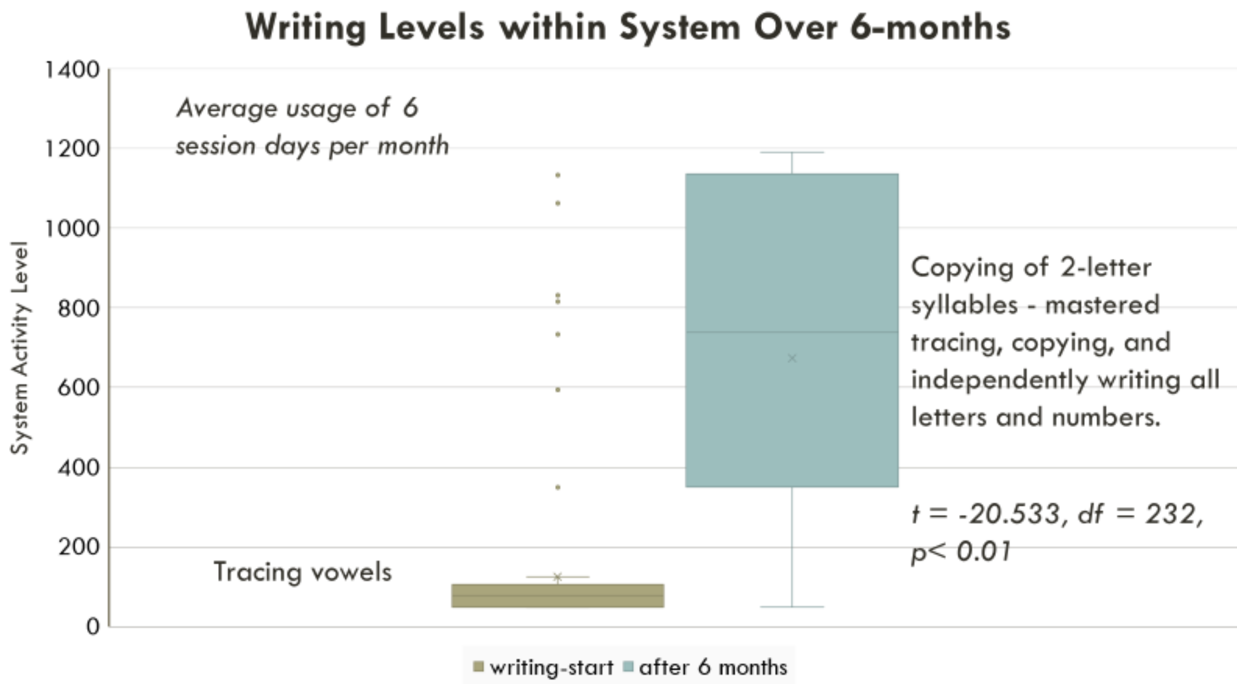

Figure 19: Students writing levels before (median = level 77 – tracing of numbers from 1-4) vs after testing period (median = level 735 – copying of 2-letter syllables); Average use of 6 sessions per month.

Chapter 4 – Study 1: Designing Appropriate Learning Technologies for School vs Home Settings in Tanzanian Rural Villages

4.1 Overview

Smartphone- and tablet-based learning systems are often posited as solutions for closing early literacy gaps between rural and urban regions in emerging economies. These systems are often developed based on experiences with students in urban contexts, limiting their success rates with children from rural areas who have had little to no prior exposure to technology. To explore how such technologies are used in different learning contexts, we deployed an early literacy learning application in school and home settings in a rural village in Tanzania. We used Rogoff's theory of instructional models to understand and describe the interaction between learners, adults, and peers. We found that in the presence of a school teacher, the instructional model was primarily "adult-run" where information was almost entirely disseminated by the teacher, while in home settings, the instructional model was similar to a "community-of-learners" model where children collaborate with other peers and adults to achieve their learning goals. We use these instructional models to surface six themes of support and scaffolding that were expressed differently across settings and discuss the benefits and drawbacks of the instructional models observed in providing support across these themes.

This work was part of a larger, multi-year, multi-site project exploring how tablet-based learning can support early literacy in rural contexts in Tanzania. In this chapter, we describe rich data collected as part of this project from different school and home scenarios across several weeks. With it, we explore the types of support that peers and adults provide in these environments. These scenarios include observing how students in grades K-2 learned with technology in the presence or absence of teachers, family members, and other adults; in the school or home environment, and in peer groups or working alone on one tablet. Within Rogoff's framing, we make the following contributions to educational technology designers and developers as they design for low-resource, rural contexts:

- We provide rich insights on the prevalent instructional models in school vs home environments and the types of support that peers and adults provide for children learning with a tablet-based learning system in rural, low digital literacy contexts in Tanzania;
- We discuss the effects of these different instructional models on the design of technologies targeted for home or school use in similar demographics.

4.2 Context

We conducted this study in partnership with a school in a rural village in a Northwestern region of Tanzania. Members of the international research team had been traveling to this region for over six years to engage in a variety of projects and were familiar with the local conditions and context. Section 3.2 shows the learning applications used in our study. Swahili was the common language in the village, and all children and adult participants in our study spoke Swahili fluently in addition to varying levels of English. Although we were not able to obtain the educational level of the participants' parents, we were able to obtain their occupation from the school records: 36 farmers, 6 shop owners, 3 teachers, 1 doctor, 1 nurse, and 1 driver. The village had two primary schools (grades K-7) – a private school that cost $350.00 USD per year to attend, and a government school with free tuition but for which parents were still responsible for certain fees, buying uniforms, and school supplies. In this study, we worked primarily with the private school students but also worked with some government school students in the home sessions.

The village itself was quite limited in physical and technical infrastructure. At the time of data collection, there was limited electricity and no running water in the village. We visited the village center almost daily to buy supplies, inform families about our study and obtain consent, and regularly patronized the only shop in the village with a desktop computer offering computing and printing services. The village center also had shops that provided phone charging services – most of the phones we observed were feature phones without internet connectivity. Three different mobile network providers serviced the village, and we purchased SIM cards from all three networks to determine the network with the fastest data speeds. The fastest network speeds in the village was EDGE (Enhanced Data rates for GSM Evolution) with download speeds ranging from 120Kbps to 384Kbps. We did not observe any tablets in the village either in home, school, or public settings throughout the duration of our stay.

4.3 Data Collection

Before each session, the children were given an overview of all the available learning activities. We were especially interested in observing how they engaged with learning technologies in different social and support settings in natural ways, therefore they were allowed to navigate to any activity they wanted, without any specific adult direction. To ensure that we observed a sufficiently broad sample across settings, we structured our observations into 30 discrete sessions during which children engaged with the tablet software. Each observation lasted about 1.5 hours. In these sessions, we observed a total of 48 unique children over two weeks. This included 26 girls and 22 boys from grades K-2, who were aged 4 to 11 depending on year of entering school. Of the 48 children, 40 children were currently enrolled in the private school, and the remainder were siblings enrolled in the government school or with no schooling at all. Consent (in Swahili) and research approvals were obtained from all learners, parents/guardians, the school administration, and the village council.

We observed the children in different social settings. Table 2 shows a breakdown of the number of sessions in each experiment scenario. All sessions were video recorded, with two members of the research team independently taking field notes for each session. Following several sessions, we reviewed our observations with the teachers to contextualize our understanding within the local cultural context. The school sessions were conducted in an unused room at the school, and a teacher was present for just under half of the sessions. For the home sessions, the schoolteachers asked parents for permission for us to

Experiment Scenarios	**School (22 total)**	**Homes (8 total)**
Adult Present	9 (41%)	7 (88%)
Individual (vs Shared) Tablets	8 (36%)	2 (25%)
Single (vs Mixed) Gender	5 (23%)	7 (88%)
Learners with prior exposure to system	13 (59%)	8 (100%)

Table 2: Breakdown of experiment sessions and scenarios

come to their houses and watch their children using the tablets. As a result, all the students in the home sessions were students of the private school or their siblings.

4.4 Data Analysis

Three members of the team then reviewed the videos, notes, and observation logs from all 30 sessions, and identified emergent themes related to the types of learning support that adults and children provided at home and school, following a grounded theory approach. Seven themes about types of learning support clearly emerged, but with their relevance and nature varying across home and school contexts. Next, we split the sessions equally among 3 members of the research team, and each member reviewed the videos and the session observation logs to categorize student interactions according to these themes, as in [43].

We then triangulated our observations related to these themes with logs captured by both researchers in the field, debrief recordings, follow-up interviews, and photographs to ensure that all evidence were mutually supportive [119]. These interactions were aggregated in a shared working document, and after all sessions were categorized, all members of the team each reviewed the findings for all 30 sessions, discussed all areas of disagreement, and re-categorized findings as agreed upon by the entire team. As a result of this process, we collapsed one theme (labeled collaborative problem-solving) into knowledge support, leaving six themes noted below. We worked with native Swahili speakers from Tanzania to help translate interactions that occurred in Swahili, as well as provide insights on the cultural underpinnings of those interactions.

4.5 Findings

The themes identified through our grounded theory analysis include activity switching support, application support, domain knowledge support, modeling, gesture support, and permission to engage. Figure 20 shows a summary of the relationship types, models of instruction, and the behaviors observed while learning with tablets in school and at home. **All these themes can broadly be categorized as either digital literacy support, application specific support, or domain knowledge support**. Below, we describe the findings by the type of interactions and the environments in which they occurred.

Child interacts with:	Location of interaction: School	Home
Child	Relationship type: Peer Behaviors: Role modelling Knowledge support Activity switching Gesture support Application support	Relationship type: Siblings Behaviors: Role modeling Gesture support Application support
Adult	Relationship type: Teacher-student Behaviors: Knowledge support Permission to engage Activity switching Gesture support Application support	Relationship type: Parent-child Behaviors: Gesture support Knowledge support Application support

Figure 20: Summary of Research Findings Showing Relations, Model of Instruction, and Behaviors Observed

4.5.1 Child-Child Interactions

Given the common expectation for child-led approaches to educational applications, we first wanted to understand whether and how children supported one another in learning. We found great variation in the emergent instructional model during child-child interactions in our study, depending on whether they were at home or at school, and, when at school, whether the teacher was in the room or not. In line with prior work, in school settings, the common practice was for a teacher to oversee all learning practices in an "adult-run" model [164]. At school, we found that children deferred to teachers for support, even in the presence of a peer who could provide support. Without a teacher in the room, peers in school were more actively engaged in supporting each other (even without being explicitly asked for help).

In children's home environments, however, the emergent models of instruction observed were primarily child-run and community-of-learners models. At home, sibling behavior centered around observing each other and reacting to each other's issues, offering help only when explicitly asked. Siblings interacted with each other only when they had to share a tablet, or when they noticed another family member receiving many error messages. They were generally less likely to proactively provide help to their siblings, unlike our observations of peers in school (with no teacher present, that is). The following sections provide more detail on the types and methods of peers' support observed during peer and sibling interactions without adults present.

Activity Switching

Activity switching support was the most common type of support we observed in school peer-peer interactions. Overall, we found this behavior in 26 sessions across all the experiment scenarios. In peer interactions, this support was initiated by the student who needed help, unlike the within-application help-seeking, which was more indirect. They appeared to be either tired of navigating the same activity multiple times, had mastered the activity, or wanted to switch to the same activity as their friend. Peers helped each other switch in creative ways. In a few sessions, students switched activities by physically swapping tablets with one another, especially if the person next to them was playing a game that seemed more interesting. In one session in school, a girl was trying really hard to figure out the activities by herself without requesting help. She only asked for help when she was tired of her current activity. When a friend helped her switch, she focused on her tablet and did not request any more help, even after struggling with navigating the activity, in line with the lack of explicit help-seeking described earlier.

There were other instances where learners reached over and switched activities for their peers without being asked to. As one might expect, not all peers were receptive to this type of directive, forceful activity switching, particularly when it happened without their consent. This unsolicited help often occurred when a peer wanted their friend to join them in the same activity so they could figure it out together. In some of those instances, students seemed slightly irritated by their peer interrupting their activity, so they either returned to their original activity, or physically moved away from their peer. However, these incidents were rare compared to most other sessions where peers needed help switching activities and seemed grateful for the unsolicited help.

At home, we did not observe any siblings helping switch their sibling's activities until it was very obvious that help was needed. There were several home sessions where we watched kids look exhausted from navigating the same activity multiple times, with a sibling right beside them engaging with multiple activities, but never helping them. After trying multiple times to switch applications (but somehow always re-selecting the same application), one older sister (who was in high school) finally stepped in to help her brother navigate to another application. In another home session with two boys, the younger sibling abandoned his tablet a few times and laid on the floor as he had repeated the same activity over twenty times. His older brother had watched him lie down a few times, and then finally reached for his tablet to switch activities for him. Unlike peers in school, siblings and other family members at home generally allowed children to navigate the tablets without interruption even through obvious struggle (except in shared tablet situations), until it was obvious that their sibling could not do anything else without their help. This reflects the greater autonomy of the community-of-learners model we witnessed in at-home learning settings [164].

Application Support

We classified all interactions directly related to showing a student how to navigate a single application under Application Support. We found evidence of application support in 18 sessions, across both home and school settings. Peers in school generally provided this support by navigating their own applications on their own tablets, while showing their friends the screen. It generally arose from one child being stuck in an application and physically pulling someone to their device or looking at someone and then back to their tablet to indicate that they needed help, or, more rarely, explicitly asking for help from a peer. Peers also watched the students beside them intently to see a model of application support. However, as we will discuss later, this support did not always occur with a teacher present. In school settings, we watched students get stuck, but persist with an application without quitting (sometimes for up to 45 minutes), until someone stepped in to help them. The kids at home did not show the same type of persistence as those in school when they were stuck. If a more knowledgeable person did not step in to help them in time, they generally abandoned the tablet rather quickly, and joined another group of siblings with a "functioning" tablet.

However, application support was not always consistently provided in child-child interactions, whether in school or at home, even if it was sought by learners. There were some instances where children reached out for help but were ignored by their peers or siblings. One girl tried repeatedly to get help with navigating an activity without luck; after a while, she laid her head on the table and fell asleep. The consequences of children not receiving needed application support included their inability to advance to a new activity, or in some cases, losing interest entirely and disengaging with the technology, in line with Nelson-Le Gall's work on disengagement if help sought was not provided [63]. Among children with adequate digital literacy, these consequences may be less severe. However, considering that adults in rural areas might have similar or lower digital literacy than their children, lack of support from peers in this area may lead to complete abandonment.

Knowledge Support

Knowledge support among peers, that is, help with understanding the literacy or numeracy domain material rather than application mechanics, was evident in almost every session (25 sessions). Unlike studies such as [124], however, we did not find evidence that more knowledgeable children *taught* their peers a new domain concept. Instead, they primarily provided support by demonstration only, without any domain-related explanations. Interestingly, while we did observe this behavior in school sessions with a teacher, we never observed this behavior when the teacher was physically present in the room. Rather, the children waited until the teacher left the room before they engaged with one another in any way. We observed that the teachers in school often discouraged children from interacting with one another. One teacher told us in an interview that the children were not encouraged to collaborate on their work, and therefore, they may consider this type of interaction cheating. This might explain the lack of peer support when teachers were present. Unlike peers in school, when siblings at home chose to collaborate, they did so freely in the presence of adults (their parents) without hesitation. This attitude even carried over to the classroom when the teacher was not present. In one study session when parents visited the school, peers freely interacted with each other without paying attention to the parents in the room.

In a few select cases, knowledge support was done through collaborative problem-solving. This most often involved individually navigating to the same game on multiple tablets and using different strategies to figure out a problem, or children abandoning their own tablet and all migrating to a single tablet. In the latter case, while the deliberation about the problem-solving was collaborative, only one child was interacting with the application at a time. The responsibilities were often divided between children, with one performing the gesture on the tablet, and the other saying the result aloud, or multiple children touching different parts of the same screen and trying different gestures. In one example, a group of boys were tasked to write 'A'. When the teacher left the room, the children talked with one another to figure out how to write the letter. They tried different strategies on their individual tablets until one boy wrote the letter 'A' without lifting his finger. He shook the second boy's arm and demonstrated writing the letter 'B' while the other boy watched. After this, both boys navigated the letter writing activity without issues.

In most other cases, the interactions we observed around knowledge support often involved the helping peer or sibling simply providing the answer or doing the gesture on their peer's tablet without any accompanying explanation of the meaning of the action, in contrast with conventional models for collaborative learning. In some sessions, the initial impulse to collaborate around one tablet led to the children (boys especially) physically struggling to take primary control of the tablet. Sometimes this was due to learners holding different goals within the same activity, and sometimes the multiple finger input described earlier caused input recognition errors. As a result, often the devices were dominated by the strongest child. Even when the children were successful in keeping control of the device itself, some of the children accomplished their goals by physically holding the finger of another child above their tablet and making them tap what they wanted. Additionally, boys and girls were much less likely to collaborate if paired in the same session at school. There was only one session involving a girl and boy that any interaction occurred and those were related to application support and activity switching rather than knowledge support.

Modeling

Finally, we observed a passive type of support, *modeling,* that was utilized by peers to achieve the other types of peer supports without directly interacting with one another. We categorized all instances where children learned by explicitly watching others under *modeling* behavior. These behaviors were present in 18 sessions across all the experiment scenarios. In all observed cases, children learned how to engage with the activity by watching another child, and this was most prevalent for gestures and activity navigation rather than knowledge support. Children were not just watching aimlessly, however; we saw evidence that just by watching one person navigate an application even for a few minutes, they were able to understand enough to engage by themselves or progress through something new. This is in line with what Rogoff describes as "intent participation", where learners observe a more knowledgeable other and adopt their behaviors themselves, in contrast with more explicit teacher-directed instructions [164]. The structure and teachers' expectations in the classroom context, instead, may not allow for such autonomous observational learning.

For example, at one home session, one boy (B1) was successfully navigating a counting game. There were siblings gathered around watching him - some enrolled in the other public school in the village, and others with no formal schooling experience. After 10 minutes of B1 navigating the same application, we handed a tablet to a boy enrolled in the public school (B2) so he too could try out the tablet applications. On his tablet, we selected the same activity as B1 was playing, and he immediately started navigating the activity without any issues. After three rounds of B2 in the same activity, we selected a different activity with similar application mechanics, and he was again able to successfully navigate it.

Although such modeling behaviors can be extremely beneficial, they are only effective when successful behaviors are demonstrated. In our data, children also used erroneous behaviors, particularly with respect to tablet gestures, and the other children watching then copied those unsuccessful gestures. The children's (lack of) digital literacy was a serious barrier to engaging with the applications without adult support. There were several children in our study that could add and subtract numbers, and read fluently, but could not navigate basic counting or letter identification applications. While the tap gesture may seem intuitive to application designers, most of the children in this study could not perform a "simple" tap gesture until they were explicitly taught. Students either pressed the screen too hard or too long, or rubbed parts of the screen in circular motions, as if they were wiping something off with their finger. There were therefore several cases in child-only sessions where the researchers eventually stepped in by the end of the hour to provide gesture guidance due to the lack of progress with a purely modeling approach.

4.5.2 Adult-Child Interactions

In contrast with the child-run expectations of many learning application designers, we primarily observed an adult-run approach to learning at school, at least when the teachers were in the room. Teachers were proactive in ensuring that students stayed on task, providing them with support for applications, activity switching, and gestures, through providing children with explicit permission to engage with the devices and by providing children with explicit pedagogical instructions.

At home, however, the model of instruction observed in the presence of parents was more similar to a community-of-learners model than the adult-run model in school. During our time in the village, we routinely observed children talking, laughing, and playing with and around their parents, and it was no different during the home observations. The parents sometimes watched their children use the tablets, chatted with other adults or did chores around the house while children were learning. Unlike teachers, parents acted as interested observers; they sat near their children and watched them use the tablet, but rarely if ever proactively intervened if the child was stuck and did not actively monitor whether their children were making progress. The following sections provide more detail on the types of support adults provided children, and the methods by which adults provided that support.

Permission to Engage

Although prior work would suggest that students' natural curiosity would have motivated them to engage with the technology (as in [28,124]), we found that at school they needed explicit permission from adults to do so. In contrast to child-child interactions, therefore, an initial function of support that a teacher provided was explicit permission to engage with the tablet. At school, students always waited until they were given verbal and often physical permission before they touched it. We observed this in all 8 sessions that had no children with prior experience interacting with the application.

For instance, in one session with two girls (G1 and G2), we placed a tablet directly in front of them and they immediately looked away and avoided eye contact with it. Over 10 minutes, we prompted them by turning it on, starting an activity and placing it in front of them, showing them an example of how to play, and they still did not touch it. We considered the possibility that our physical presence in the room caused this behavior. We then left them alone with the devices for another 20 minutes – they had still not touched them when we returned. From video recordings, they appeared more relaxed when we stepped out of the room. However, rather than engage with the tablet, they started playing with a toy lion that was on the table. This finding is corroborated by evidence that the students behaved very differently with the teacher in the room compared to when only researchers were present. With researchers and recording equipment in the room, the students often talked very loudly, laughed at each other's jokes, and in a few sessions broke out in physical fights in the struggle for control of the tablet. As soon as the teacher walked in, learners would readjust themselves, sit quietly, and engage with the tablet in a very orderly manner. When we returned to G1 and G2, we prompted them again to use the tablet, and played another game in front of them, but they did not use the tablet until a teacher gave them permission.

In another session with the teacher present, we offered the tablet to the children but they did not touch it. The teacher then said to them in Swahili, "*this is it… touch what I told you okay?*" and physically pressed their fingers on the tablet as if tapping on the screen. At this point, they began engaging with it fully.

Gesture Support

Prior to helping learners navigate the application, we observed parents and teachers explicitly teaching children how to perform gestures (e.g. how to tap) in 13 sessions – both at home and in school. Unlike peers, adults demonstrated on the table side by side with the child, or physically held the children's fingers to teach correct gestures.

In a session with a number writing activity (Figure 2 - Left), the teacher pointed to the space where a girl was supposed to write. She thought he meant she should tap it, so she tapped it and nothing happened (this girl was in Grade 2, and later demonstrated that she could add and subtract numbers using her fingers). The teacher asked her a question and she responded, "Sifuri" (0) – the number physically shown on the screen for her to write was '0'. She then tapped '0' repeatedly, but nothing happened. Again, he whispered something (inaudible), pointing over the writing space. She now started tapping all over the writing space without luck. Finally, he physically picked up her finger and wrote '0' in the writing space. After this, she navigated the rest of the activity successfully.

Even after they were shown how to tap successfully by an adult, many children still unsuccessfully experimented with using other gestures or attempted using other parts of the body (e.g. lips, fists) to select items (see Fig 21).

Activity Switching

In sessions with teachers present, support for activity switching was initiated by the adult when they felt the learner had stayed in the same activity for too long, or had mastered the current activity and needed to practice something else in the application. In a session in school with two girls on a shared tablet, after watching the girls play the same activity for a few minutes, the teacher got up and said in Swahili, "*Play that game. Once you finish, go for another*." The girls finished the activity, returned to the home screen, then turned to him and said, "*Ready*." He got up from his seat, and then explained the mechanics of the new activity to them so they could start to play.

At home, however, the adults did not actively monitor their children's progress, and thus did not proactively interrupt and help them switch to another activity. In one of the homes, we gave the children two different tablets to interact with. Their mother and older sister were present for the session. Most of the kids gathered around a boy who was in the 5th grade in the local government school and was successfully navigating through different activities. The other tablet was with another child who played the exact same activity (counting 1-10) for over an hour. None of the members of the family, siblings or adults stepped in to intervene. Originally, most of the children were gathered around him, but they migrated to the 5th grade boy who was clearly making better progress. This is indicative of the fluid participation in the community-of-learners model, where learners take autonomy for their own learning (like the child playing the same activity for an hour) and observing other, more knowledgeable community members without proactive support from older adults.

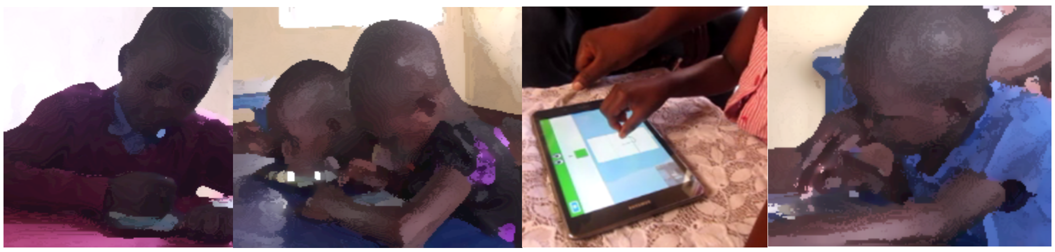

Figure 21: (L-R) Students performing incorrect gestures; Adults teaching correct gestures at home and in school settings

Application Support

Rather than simply demonstrating how to navigate applications to students, teachers gave support by explaining the function of each of the buttons or icons in the activity, and their purpose. The following excerpt provides details on how a teacher provided application support (as well as knowledge support) for a session with three girls on a shared tablet without prior experience with our application. These utterances were translated from Swahili.

The teacher explained a counting game … He said, *"You touch as you count",* and they started taking turns to tap on each dot, counting after each tap. The game was designed to say aloud the number of dots after each tap. He explained after the first tap in Swahili, *"it just said '1'"*; after the second tap, *"it just said '2'".* He then asked the girls, *"how many*?", and they responded in chorus, *"two".* He told them to tap the last dot, and pointed out how to proceed to the next screen. The screen now had four dots on it, and he said, *"A dot has been added. How many dots do you see now on the screen?"* They responded, *"four,"* and he instructed them to touch the dot and count again. They finished the activity and proceeded to a new one (see Figure 13). Pointing over the '+1' button, he said, *"you add, and count, and touch this."* After they added up to the number 10, he said pointing over the '-1' button, *"now if you want to take away, do that by touching this button here."* When they subtracted down to the number 1, he pointed over the refresh button and said, *"you touch here and it takes you back to where you started from."*

Knowledge Support

We found evidence for knowledge support in 7 sessions, provided by teachers and older family members. In interactions with adults, explicit knowledge support was provided when the children did not understand the fundamental concepts the activity was trying to teach. This was mostly evident in the addition and subtraction activities, as well as the writing activities. In school settings, the teachers provided this support simultaneously with application support – they showed the students how to navigate the applications while explaining their function and they also verbally provided explanations or elaborations on the domain knowledge the application was trying to teach.

At home, adults and family members most typically provided this support without explaining the reasoning behind the concepts. However, one parent (who was a teacher in the government school) provided further detail to his daughter when it was clear that she understood the game mechanics, but did not have the knowledge to navigate it successfully. His daughter knew how to count her numbers, but did not know her shapes. To assist her, her father told her to listen to the prompts carefully – in Swahili, the shape names include the number of sides e.g. 'pembetano' = pentagon; tano = 5. Her father told her to listen for the number in the shape's name, and count the number of corners on the different shapes on the screen. She followed his instruction, and got the answers to the shapes with numbers in their names correctly.

In the one session where parents visited the school, the parents also became collaborators involved in trying to figure out how to do a literacy activity. Sometimes, they asked the children to try different things, while trying to audibly come up with a theory as to why that was the right thing to do. When the children finally figured out how to navigate the activity successfully, everyone smiled in satisfaction, parents and children included. It is possible that the more formal school setting influenced the approach they took in the interaction.

4.6 Discussion and Conclusion

In this work, we found that different models of instructions emerged when using the tablet in school and home learning spaces. When adults were not present, the child-run model of instruction promoted by many educational technologies for use in rural Africa was (unsurprisingly) prevalent in both home and school settings. In the presence of adults, however, adult-run models of instruction were highly prevalent in school, while community-of-learner models were emergent at home with parents. In many cases, these models were complementary to one another, providing different types of structure to the environment while still benefitting the learning experience. Our work provides several novel contributions to the body of literature on instructional models.

Most importantly, we show that children and adults provide different kinds of support that are beneficial for different aspects of tablet-based learning interventions in this context. The children in our study provided support by either showing their peers how to accomplish a task or doing the task for them, mostly when they were explicitly asked for help, or by indirectly allowing their own work to be observed. This hands-off approach of helping only when asked allows for the opportunity to explore the device and learning applications without inhibitions. Also, we found that children were able to support one another with issues related to digital literacy if at least one child learned the correct behavior. On the other hand, the teachers in our study supported students with the acquisition of new domain knowledge in a way that the children were unable to, consistent with prior literature [148]. Teachers were also able to successfully support the acquisition of digital literacy that is critical to initiate engagement with a new technology. This was likely due to teachers typically owning screen-based phones, while children in this context are rarely given permission to use the family's technology if available. In addition, teachers provided "intelligence" to the learning process (even without prompting) by knowing when to advance children to a harder task or when to keep them practicing the same activities. Without this support, children who finally mastered an activity were unlikely to switch to any activity that challenged their current knowledge without external intervention.

However, unlike previous studies, we show that having a teacher was not always beneficial. With the presence of a teacher in the room, children automatically relegated the responsibility of activity selection, digital literacy support, and even device exploration to the teacher, even when their friends could have helped or they might have figured it out themselves. Prior work suggests that the expectations and norms for help-seeking and help-offering in school are socially and culturally constructed, highly influenced by cultural norms and inflected by the norms set within each class by individual teachers [63]. Therefore, in a culture where teachers are the primary source of authority in school settings (such as in our work), peers may be less likely to take on the role of a teacher providing explicit explanations in support of domain knowledge mastery. In addition, collaboration among the children with a teacher in the room was virtually non-existent. In the absence of teachers, children demonstrated on several occasions that they could work together to accomplish their goals. However, peers and siblings, even when eager to collaborate in school, may not always be able to do so without having norms and expectations for collaboration established by a teacher. Given the central role that teachers play in establishing norms and expectations in schools, educational technologies targeted for schools must be designed in a way that not only accounts for the needs of the children, but also accounts for the role the teacher plays in supporting their use of such technologies, similar to [52,79]. For example, activities that require collaboration may be ineffective in school settings without instructions for teachers on how to scaffold that collaboration. In contexts such as the ones we studied, collaboration can might be considered as cheating; therefore, the physical presence of a teacher might prevent the students from collaborating, even if that is the only way to successfully complete an activity. Even engaging with the educational technologies in the first place may not be guaranteed without the explicit permission of the teacher.

We propose first an acknowledgment of the role that peers, siblings, parents and possibly even teachers are likely to play in a learners' engagement with an educational technology, even when the intent is to support a purely child-run model of learning. Second, our findings point towards the need for the targeted design of learning scaffolds that are appropriate for supporting these varied roles, including explicit pedagogical feedback, adaptivity for supporting mastery learning, and structured models of collaboration and co-engagement. Learning applications that may be used in schools must consider teachers as an important factor in their success and understand that teachers are often the primary source of authority in classrooms. School-focused applications should take advantage of the support and scaffolding teachers provide and communicate the value and process of collaboration activities in contexts where teachers consider it to be cheating. Finally, school-focused applications that rely on children's natural curiosity to independently explore activities and gaming mechanics to achieve mastery may be less successful due to children's expectation of explicit rules guiding their behavior, and a desire for explicit permission to engage with the application.

Applications designed for home use on the other hand may be a good target for activities that require collaboration and uninhibited exploration by children. However, without the expectations for explicit guidance as with a teacher, children may be more likely to do activities for their peers rather than teach them, avoid challenging activities, and dominate the learning experience of certain peers. Scaffolding and feedback must be offered much more frequently than school focused applications, as without them, they will likely not receive this support from anywhere else. Finally, home-focused applications may be much more susceptible to dropout. Children did not show nearly the same resilience and persistence through struggle at home as they did in school, and parents may not always be present to provide explicit instructions, so difficulties related to digital literacy and application mechanics may have even more negative effects at home. Applications may need to be designed to be even more engaging and enjoyable to prevent dropout, unlike school-focused applications where the mere presence of a teacher will almost guarantee student engagement.

Finally, it is worth reiterating that children from low digital literacy communities face a much steeper learning curve when trying to learn with content deployed on tablet devices. In urban contexts, children engage with smartphones, cameras, and video games at very early stages of their cognitive development [61]. This allows developers to focus on designing the appropriate mechanics of learning applications for their developmental needs. However, this presumed digital literacy can be problematic when designing learning applications for rural areas. Outside of adult support, modeling was one of the most effective ways for children to learn about application navigation and appropriate gestures, but this modeling did not always happen in a sufficient or timely fashion. In light of this, solutions such as a video of a child interacting with an application, with both the application, and their fingers in close view may be effective for teaching appropriate gestures and application navigation.

Our findings are limited in several respects. Our results are applicable to rural, low digital literacy contexts similar to that of our study. In addition, we acknowledge that our physical presence might have caused the children to behave differently than if there were no adults in the room. To assess its impact, we reviewed video footage of sessions when were absent from the room. Although the children seemed more at ease with one other, their interactions with the tablet were like the sessions with researchers present. As discussed above, children's behavior *did* change based on the teacher's presence in the room. Thus, while our presence in the room likely caused some original discomfort, it did not have nearly the same impact as the presence of their schoolteacher who they were very familiar with. Also, we are aware that observing the children for a longer period, as in [164], will provide even richer socio-cultural insights about how children engage with learning technologies in similar demographics. However, these early insights are critical for supporting the needs of children in rural areas to enable them to overcome the steep learning curve they face with first engaging with learning technologies. Finally, all the parents with children in our study valued formal education for their children (as indicated by their enrolling them in schools and consenting to our study). Our insights may be different with parents who value other vocations such as farming, cattle rearing, etc. over formal education.

These findings elicit several questions for future work: How do we design children's interactions with educational technologies to ensure that parents' and teachers' beliefs about collaboration do not discourage children from engaging in meaningful collaborative discourse? In cultures where teachers are regarded as the authorities in the classroom, can we design interactions that encourage children to also see themselves as knowledgeable parties, to scaffold them in providing explicit instructional support for their peers? This is important because adults with formal education experience or digital literacy may not be available to provide this support in the rural communities that most need educational intervention. In our study, peer modeling was common way for children to overcome many obstacles - how do we promote this type of support while encouraging deeper interaction? As we answer these questions, we can leverage all the support available for gaining fundamental skills through digital media in rural environments.

4.7 Takeaways/Considerations for Learning Application Design and Future Studies

Based on the insights gained from this exploratory research study, we will consider the following key points in the design of our learning application and future research studies:

1. Students need explicit support to overcome issues related to their lack of basic digital literacy, application specific support, and domain knowledge support.

2. Modeling correct behaviors is an effective way to provide application support to children in this research context. The current version of our learning system already provides this support by playing a video showing students how to successfully navigate each application along with explanations of all the different application features. Students see a modeling video before they experience any new application for the first time.

3. Students need support with switching from one application activity to another, however, peers may not effectively provide this support as they made navigate to applications that students are not cognitively prepared for. The current version of our system already provides this support by monitoring student performance, interspersing the same knowledge components using multiple learning applications, and presenting only two cognitively appropriate choices to students (rather than the entire activity library), with application screenshot-based icons to allow them some choice without the compromising their learning gains.

4. Students may hesitate to interact with learning technologies without explicit permission from a teacher. Research studies that require students to interact with learning devices should be setup to allow teachers provide explicit permission to students before the beginning of the study sessions (especially for children without prior technology experience).

5. In this context, students persist through difficulty much more in school environments (even in the absence of a teacher) compared to their home environments. As a result, struggle behaviors related to the support types observed in this study are likely more evident when conducting experiments in school settings rather than in home settings.

6. Knowledgeable peers are likely to be more present in school settings compared to home settings, therefore, experimental studies investigating help-seeking behaviors are more practical to conduct in school settings.

7. In this research context, peer-peer help-seeking and collaboration interventions will likely be ineffective in the presence of a schoolteacher. Students showed that they were willing, and in come cases able to support their peers, but only when a teacher was not physically in the same space.

8. Due to issues related to children's digital literacy, help is more distributed in this rural learning context compared to their urban counterparts. For example, students who can provide knowledge support may not be able to provide application or digital literacy support for their peers. Therefore, when designing help-seeking interventions, identify students who can provide knowledge support separately from those that can provide application support and vice versa. Also identify students who can provide both kinds of support if it is unclear the type of support a student needs e.g. not interacting with the device despite explicit permission from the teacher.

9. We observed that in this cultural context, boys are unlikely to interact with girls while learning with technology even in the absence of their teachers. Forming mixed-gender experimental groups reduces the likelihood of prior student friendships affecting student interactions during experimental sessions; single gender groups may maximize student comfort with interacting with one another.

10. Finally, it is not guaranteed that peers will provide support for one another in a timely manner without explicit instruction or scaffolding. Future studies should investigate ways of explicitly instructing students to provide support for one another without hindering the overall learning experience.

Chapter 5 – Study 2: The Effectiveness of Publicly vs. Privately Assigned Group Leaders among Learners in Rural Villages in Tanzania

5.1 Overview

Research studies show that teachers increase the success of education technologies in rural settings by supporting students via technology support, domain-relevant explanations, enforcing discipline, and maintaining student engagement. However, a teacher's presence hinders student collaboration in some cultural contexts, and some students may not have a teacher or knowledgeable adult who can provide this support. We conducted an experiment with K-1 students (N=36) in a rural Tanzanian village, where we trained students to provide technology support for their peers under different experimental conditions. We found that with basic technical training and social awareness of the assigned leaders, students can indeed provide peer support in the absence of a teacher, and additionally enable collaboration. We challenge the popularly held notion that natural leaders will emerge and support students' technology and learning needs without adequate training and discuss the implications of our findings in the deployment of technologies in similar socio-cultural contexts.

Research such as [99:20] has provided limited evidence that when children are equipped with technical skills, they can naturally emerge as leaders and provide support for their peers, without having an official assignment as a group leader. Other studies show that behaviors differ when leaders are assigned rather than emergent [216] We investigate whether this finding applies in a different cultural context by equipping children with basic technical knowledge, and asking them to support groups where they are officially assigned as the group leader. We deployed an Android tablet-based learning system with *unsupervised* groups consisting of a child with domain knowledge and technical competency, their closest friends, and randomly assigned peers. We vary the experiment conditions by publicly assigning a leader in some groups, and not in others. We use these observations to answer the following research questions:

- To what extent do knowledgeable children take on the role of a leader within a group of learners, when either privately or publicly assigned the authority to do so?

- What kinds of support assigned leaders offer across social factors such as gender and close friendships in this cultural context?

5.2 Context

This study was conducted in partnership with a Swahili-speaking, rural village in a Northwestern region of Tanzania. Members of our research team have conducted research in the region over the last three years. The village was limited in physical and technical infrastructure with inadequate power or clean water. Three mobile network providers serviced the village. Throughout our stay (and in previous visits), we observed families with mostly feature phones without internet connectivity, however, a few schoolteachers owned basic Android smartphones. We did not observe any tablets in the village homes, schools, or public settings throughout our stay. Consent (in Swahili) and approvals were obtained from students, parents/guardians, the school administration, and the village council with help from a native Swahili speaker.

5.3 Data Collection

To ensure that we observed a sufficiently broad sample across experimental conditions, we structured our observations into 24 discrete sessions during which six groups of six children each engaged with the tablet software. Each observation lasted about 1 hour. In these sessions we observed a total of 36 unique children; this included 18 girls and 18 boys from grades K-1, ages 5 to 10 depending on year of entering school. Before the sessions began, we gave all the children a paper pre-test covering letter and number recognition, letter and number writing, simple word problems, and listening comprehension. These pre-tests were administered by Swahili speakers who read the questions one by one to each child and recorded their responses. We noted down the students who scored the highest and distributed them equally among the groups. Following the pretest, we ran a baseline session with each group, allowing students' natural interaction patterns to emerge.

We selected six children who performed well on the pre-test **and** quickly learned to navigate the tablet application without adult assistance. We selected the highest-scoring children as leaders just in case their peers needed domain knowledge support in addition to technical support and assigned them as leaders for each group in the experiment scenarios. We started forming the groups by asking each leader to select two of their best friends from the class - each group was comprised of a leader, the leader's selection of their two best friends, and a random assignment of three other children from the class, balancing each group by gender. After forming groups, we informed the leaders privately that they performed the best in the pre-test and with navigating the system and were now responsible for supporting their group. We conducted a training session with all six group leaders to reinforce practices of navigating each application without assistance, as well as performing basic troubleshooting tasks e.g. helping a peer return to the learning application if they exit accidentally. After the training, all leaders could navigate the tablet and application without assistance.

Group #	Age Range	Score Mean	Score SD	Score Range	Leader's Score	Leader Condition
1	5-10	34%	23%	8-72%	72%	Privately Assigned Leader
2	5-7	46%	14%	42-60%	60%	Privately Assigned Leader
3	5-7	46%	12%	32-62%	62%	Privately Assigned Leader
4	6-9	72%	14%	52 - 90%	90%	Publicly Assigned Leader
5	6-8	79%	11%	65-93%	90%	Publicly Assigned Leader
6	6-8	71%	13%	55-88%	88%	Publicly Assigned Leader

Table 3: Group Information with Summary of Pre-Test Scores, the leader's Score, and Experiment Condition

Before the start of the sessions, we reminded the leader of their job to help their peers, as no adults would be around. For 3 groups, we shared this privately with the leader so other group members did not know the group had a leader (privately assigned leader condition), however, in the other 3 groups, we made this announcement publicly, informing the group that the leader would answer all questions they had (publicly assigned leader condition). All groups completed 4 sessions each - 1 initial baseline session without a leader assigned and 3 sessions with an assigned leader. Following the baseline, we conducted two periods of classroom observation to better contextualize each leader's natural peer interactions. leaders are summarized below as "L#"; the number corresponds with their group:

- L1: 6 y/o girl - Quiet. Answers all questions correctly, does not interact much with her peers.
- L2: 7 y/o boy - Energetic, sometimes disruptive. Tries to answer all questions asked by teacher before others can, so the teacher sits him in the back, and never calls on him to answer questions. Once when the teacher left, he ran to the front and pretended to teach the classroom.
- L3: 6 y/o girl - Usually answers correctly when called on. Observed mouthing an answer to a boy called to answer question when he did not know the answer. Usually sits with her friends in the front, who all wait for her to write an answer on a worksheet, and then copy her for in-class activities.
- L4: 9 y/o boy - Quiet in class. Does not speak except when directly asked a question, does not disrupt.
- L5: 8 y/o girl - Quiet but engages in occasional banter with friends even when the teacher is present.
- L6: 7 y/o girl - Quiet but also engages in occasional banter with her friends.

5.4 Data Analysis

No researcher or adult was present in the room with the students during the study sessions. Instead, these unsupervised sessions were video recorded from multiple angles to capture natural student interactions. The team analyzed the data from all group sessions, recording qualitative observations of the student interactions with the tablet and each other. Next, the team reviewed the videos, notes, and observation logs and identified emergent themes related to the types of help-seeking and help-giving behaviors surrounding each group leader following a grounded theory approach [43]. Six themes of student behaviors emerged: 1) student distracting the group, 2) leader addresses student distraction, 3) student asks leader for help, 4) student asks leader to help a peer, 5) student (not leader) helps another non-adjacent student, and 6) leader helps a non-adjacent peer. Next, we split the sessions equally among 2 team members for categorization according to the 6 themes. A third team member reviewed and coded all 24 sessions to validate the categories created by the other team members, breaking each session into 30 second intervals and adopting a partial-interval recording method [74]. Finally, we triangulated all observations related to these themes with logs captured by researchers in the field, debrief recordings, follow-up interviews with teachers, and photographs captured on site to ensure that all evidence were mutually supportive. After all sessions were categorized, all members of the team each reviewed the findings for all 24 sessions, discussed all areas of disagreement, and re-categorized findings as agreed upon by the entire team. We worked with native Swahili speakers from Tanzania to help translate interactions, as well as provide insights on the cultural underpinnings of those interactions. This study design and data analysis methodology has been used and validated in previous CSCL research studies e.g. [146].

5.5 Findings

5.51 Baseline Student Behavior

As soon as the sessions started and the adults left the room, the children smiled at each other, looked around briefly, and then started interacting without prompting. These interactions included sharing new activity types with their adjacent peers, sharing a funny activity, celebrating their accomplishments, singing nursery rhymes together, and even repeating spoken tablet instructions in unison. We observed lots of play (and real) fighting in the room as they encroached on each other's tablets, and children intentionally distracting each other from staying on task. If an adult re-entered the room for any reason (forgot an item, child in the session called for their help, end of session, etc), the children stopped all interactions and focused on their tablets.

Without an assigned leader, students generally provided help when **all** of the following conditions were true: 1) they noticed a peer struggling or the peer asked them for help, 2) the peer is sitting adjacent to them, 3) they are not engrossed in their own work, and 4) they knew how to help (vs trying to find a solution to a new problem). In general, their behavior mirrored the classroom observations - quiet students kept to themselves even when other children tried to interact with them uninvited, and talkative students were the most vocal (and disruptive) in their sessions. The students connected the learning application to what they learned in the classrooms - on several occasions, we observed children bringing out their notebooks from their bags to double check answers before they selected answers on the tablet. They primarily communicated with their adjacent peers, and those whose screens they could easily see. Across all six groups, we observed only two instances where a student helped a non-adjacent peer. Figure 22 shows the student seating arrangement in the classroom. Students sat in a row, all facing the same direction, allowing them to interact with their peers and see their work. There were no observable differences in how girls interacted with other girls vs boys (and vice versa), although friends seemed more likely to share funny stories and new activities with each other.

In all interactions observed under this condition, students provided knowledge-telling support to their peers either voluntarily or when solicited; they either selected the answers for their adjacent peers or told them what answer to tap without any elaboration. We observed one instance of student collaboration in this condition (and another in the publicly assigned leader condition) when knowledge-telling was insufficient. In one interaction with L5, an adjacent peer was struggling with a tracing task. After she asked L5 for help, L5 said "andika" [Swahili for "write"]. The girl followed L5's instruction, but her answer was still not accepted because she wrote beside (rather than over) the trace outline. Then L5 reached in to help but also wrote beside the outline, resulting in a rejected response. They looked for a teacher, but no one was close by, so they tried different strategies until they learn the correct way to trace on the tablet.

Figure 22: Typical seating arrangement in experiment sessions

5.5.2 Student Behavior in Privately Assigned Leader Condition

Students in this condition behaved similarly to the baseline condition. L1 remained quiet throughout her sessions, only interacting with adjacent peers, and volunteered help when she noticed a struggling adjacent peer. Since she was not revealed as the group leader, non-adjacent students did not ask her for help. When engrossed in her tablet, she ignored most requests for help even from adjacent students. This observation was consistent in all of L3's sessions as well. She freely chatted with adjacent peers, but also ignored their requests for help when engrossed in her own work. On the occasions where L1 and L3 helped their adjacent peers, *they showed very little persistence* and routinely abandoned them if their attempt was not a quick fix on the first or second try.

There were clear negative consequences when a student needed help but didn't receive it. In Group 1, a boy struggled with basic application navigation, and could hardly complete a single learning activity in all three sessions despite sitting next to L1 in one session. Also in a session with L1, a student gave up and left the session after trying for 30 minutes to start a learning activity (including asking her for help twice), while another started to wipe tears from her eyes after repeated unsuccessful attempts at getting herself back on task. Figure 23 shows a boy in Group 3 who needed help, and his reaction when he finally learns to navigate the application after receiving help from the girl right beside him (not L3). L2's behavior as a privately assigned leader was quite different from L1 and L3. In the first session, he interacted mostly with one of his best friends similar to his behavior in the baseline condition. After privately reminding him of his responsibilities prior to the next session, he spent most of his time walking around the room and helping every struggling student (similar to how his teacher behaved in his classroom), without paying much attention to his own tablet. He was only asked for help 4 times from his adjacent friends throughout the session, but volunteered help to 18 additional non-adjacent peers. When his peers noticed that he was providing this help, they called on him to help other struggling peers, and he continued to hover around their tablets to review their progress. If a peer paused briefly, he ran over to solve the problem even if they did not ask for help. Some did not welcome the constant, unsolicited help - near the end of one session where L2 "helped" a girl constantly, she shoved him away when he walked over to her. His monitoring also quickly turned into behavior enforcement. One of the activities in the learning application involved a racecar that made screeching sounds. Students quickly figured out how to exploit this sound and enjoyed producing an almost-constant screech, therefore distracting the whole group. In the first session, L2 and his adjacent peer engaged in this distraction, but by the second session, he monitored and turned off students' tablets if they tried the exploit.

His enforcement tactics became progressively stronger in each session, and he started hitting kids on the head and addressing the whole group sternly when he thought they were not paying attention. Although some children had problems with his style of help-giving, overall it had positive effects on the group. Most children stayed on task, students started calling him for help for themselves and for others, and others started to emulate him by standing up and walking around to help as well. Figure 24 shows L2 addressing a student who was distracting the group. On the average, L1 and L3 ignored 79% of help requests overall (and all requests from their friends), while L2 ignored only 33% of his requests for help (13% from his friends).

Figure 23: (L-R). Struggling boy; peer notices and helps; excitement when he gets questions correct

Figure 24: L2 addressing a student who was distracting the entire group

5.5.3 Student Behavior in Publicly Assigned Condition

Publicly assigned leaders had fewer help-giving restrictions; they generally provided help either if they were asked or if they noticed a peer struggling. Unlike L2, none of the leaders in this condition (L4, L5, L6) hovered around the entire group. Despite their working steadily and constantly on their tablets, they responded to most requests for help. The other children in the groups chatted with their adjacent peers about new activities and funny stories, and even attempted to help each other first before calling on the leader. On the average, leaders in this condition responded to requests for help 75% of the time (77% from their friends). They were able to discern when they were called for non-help requests such as discovering new application activities. L5 was even able to tell when she placed someone in an application that was too easy for them. She restarted a boy's application and placed him in an alphabet song. Immediately, she exited the application, and switched it to a more difficult story for him to read. Although the leaders were called upon frequently in the first session, the help requests decreased in subsequent sessions, suggesting that students became more proficient at navigating the tablets without the leader. By the 3rd session, the publicly assigned leaders got the same number of requests from the whole group as the privately assigned leaders from their adjacent peers. Figure 4 shows a chart of the average number of times the leaders were called upon as the sessions progressed per condition.

The biggest difference between the help offered by publicly vs privately assigned leaders was the degree of leader persistence. We did not observe any cases where the leader abandoned a student even when they could not figure out a solution. One student in Group 4 accidentally exited the application but could not open a new instance. She asked L4 for help, but he could not figure out a solution after several attempts. He started to walk back to his seat but changed his mind, knelt beside her, and kept trying. After much trial and error, she found the application switcher button and selected the learning application. Instead of returning to his seat after this success, he reproduced the problem, so he could practice the solution she discovered. Following that, he returned to his seat. Similarly, L5 spent over 5 minutes trying to help a girl with a technical issue with constant application crashes. After several unsuccessful tries, L5 left the session to seek help. The application had to be reinstalled to fix the error.

Finally, the leaders helped to maintain engagement with the learning applications. All students enjoyed exploiting the racecar game's screeches. Unfortunately, the noise distracted everyone in the group and increased off-task behavior. It caused students who were trying hard to focus to start tapping the tablet without regard for the current activity or scribbling furiously in writing activities. Unlike the privately assigned leader condition, the publicly assigned leaders initially joined the fun, but quickly worked to establish order in the groups. L4 warned the students to stop misusing the application; L5 and L6 resorted to turning off students' tablets if it distracted their group, and in one incident, L6 even seized a peer's tablet. Other members of the group began to call for the leader when someone was bothering them individually, and the leaders routinely intervened. This was an unexpected but welcome benefit of having publicly assigned leaders in the group because these interventions minimized the time that students were off task compared to the other leadership conditions.

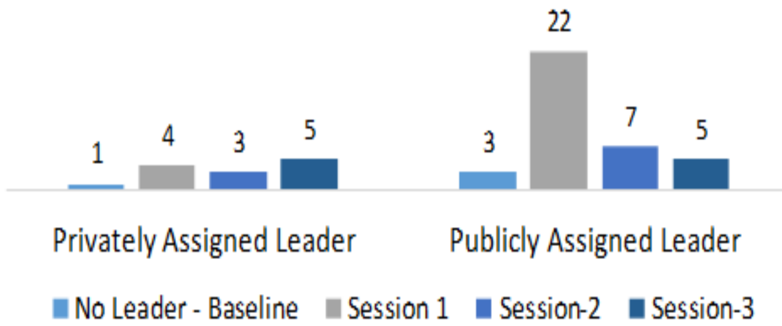

Figure 25: Average Help-Seeking Requests to in Privately vs Publicly Assigned Leader Conditions

5.6 Discussion and Conclusion

Unassisted learning educational settings are becoming more popular due to the increasing demand for education where traditional schooling facilities and instructors are scarce - our research contributes to the body of knowledge that maximizes their success. The expectation that children, without formal training or assignment, will provide support in unassisted learning situations seems intuitive given their innate curiosity, and previous findings from other cultural contexts. However, our research provides evidence that socio-cultural factors do not only affect the ways that children engage with educational technologies, but also in their willingness and ability to support one another, as well as the quality of help they provide. This is not to say that natural leaders in this cultural context do not exist - a student like L2 demonstrated his enjoyment for teaching and proctoring both in the classroom and in the experiment sessions. However, in a culture like the one we studied where teachers and adults are likely the singular source of authority, this kind of behavior may be punished similar to seating L2 at the back of the class, and refusing to call on him or answer any of his questions. We also provide evidence that children who show natural helping tendencies in the classroom (like L3 whose classmates depend on her for answers), even when trained, do not automatically emerge as leaders for their peers at the expense of their own interest. Our research shows that in this cultural context (and similar), help-giving did not vary by friendships or even gender, and students provided the best quality of support when they were trained to help **and** when there was a social expectation of them providing such support. Leaders did not just naturally emerge similar to other studies exploring unassisted learning situations e.g.[99] and [124]. Rather than expecting children to naturally provide support for their peers, such unassisted learning programs should train and educate children on who, how, and when to ask for support to maximize their success.

Publicly assigning the role of a leader conferred significant benefits to all students (leaders included). Group members, regardless of their proximity to the group leader received much needed help with the learning application, and we observed no incidents of children frustrated, abandoning the sessions, or going multiple sessions without engaging with the learning application (unlike the privately assigned leader condition). Leaders showed that they could regulate their learning and that of their peers, deciphering when a student really needed help vs when they could figure it out for themselves, and leaders became more persistent and provided better support by practicing more nuanced ways to bail their peers out of trouble, improving the collective knowledge of the entire group. These results are in accordance to previous findings that show that students' ability to influence and adjust their own cognitive and help-giving behaviors and that of others is optimal for learning and working together [222]. Another unexpected but positive effect of publicly assigning leaders was how much the leader helped to control disruptions to the group. In our experiment sessions, when one student started causing disruptions, the whole group (including those who were trying hard to stay focused) got distracted as well. Having students who automatically took the responsibility upon themselves to manage disruptions was important for maintaining student engagement. Finally, our research provides evidence that in a cultural context where collaboration is often discouraged by teachers e.g. [199], carefully designing unassisted learning environments can foster collaborative behaviors even for simple writing tasks. Further research is required to investigate how these behaviors change as the tasks become more complex, or when the students are explicitly engaged in collaborative tasks.

Our study is limited in several ways - the lack of in-depth explanations provided by students may be a factor of their age and developmental level, as well as the domain area not requiring much explanation (early math, letter identification, and early reading). Future studies should investigate these help-seeking and help-giving behaviors among older students in domain areas that require more explanations such as math and science targeted at later grades. Also, the only training children received was related to technology support. They were not trained on how to properly give domain knowledge feedback to their peers. Although, our study provides evidence that untrained students do not provide knowledge-building naturally, further investigation is required to determine the help-giving behaviors of students who are trained to give proper feedback. Finally, in our study we qualitatively observed a small group of high performing leaders across multiple sessions - these insights may be different in a larger scale study, or with students with lower achievement.

5.7 Takeaways/Considerations for Learning Application Design and Future Studies

Based on the insights gained from this follow up research study, we will consider the following key points in the design of our learning application and future research studies:

1. The physical proximity of peers to one another is an important predictor of students' help-seeking requests – students in this learning context generally ask only their adjacent peers for help when needed.

2. For students to willingly help their peers, they have to know how to help, and have the public responsibility of do so. It is important to utilize students' performance and technology experience as a basis for help-seeking recommendations, and explicitly inform students that it is their responsibility to support their peers.

3. Sometimes, students remain engaged with the learning system but struggle with application navigation so much that they are unable to complete activities. Therefore, increased activity completion rates and question completion times is a possible indicator of reduced struggle.

4. Sometimes, students accidentally navigate outside of the learning application and struggle tirelessly to get back on track. Our learning system currently provides support for this issue by enabling a 'kiosk mode' where students are restricted to navigating on only the learning application on the tablet.

5. Sometimes, students do not interact with the tablet at all due to frustration after unsuccessfully asking their peers for help. Long periods of student inactivity (hesitation), might be an indication that students need technology, application, domain knowledge support or all three of them.

6. Conferring the responsibility of help-giving on only one student provides a benefit of reduced disruptions within a group. However, it may reduce group rapport due to one student verbally and physically reprimanding their peers. Therefore, assigning help-giving responsibilities in a more equitable fashion will likely reduce instances of group leaders disciplining their peers, and maintain group responsibility for minimizing disruptions.

7. Students generally do not enjoy unsolicited help from their peers and want to maintain the agency of requesting for help when they need it.

8. Students face much less frustration in this learning context when they are aware of the specific students to call on for help, rather than just depending on their adjacent peer to support their technology learning needs.

Chapter 6 – Teacher Perspectives on Peer-Peer Collaboration and Teaching with Education Technologies in Rural Tanzanian Classrooms

6.1 Overview

Teachers are a critical piece to understanding classroom culture and practices. They create and enforce rules in the classroom and are responsible for educating students using methods that they perceive to be most effective. Therefore, creating educational technologies aimed at supplementing classroom instruction without understanding the classroom culture may lead to interventions that are underutilized or at ineffective. When researchers conduct studies with easily accessible cultural groups, gaining insights on classroom culture and teaching practices from teachers are feasible. However, in rural or remote locations with limited resources, access to teachers can be very difficult.

To compensate for these accessibility difficulties, researchers often depend on other heuristics such as systems-based theories (e.g. Hofstede's index) and unrelated research studies conducted in close geographical locations to provide insights on the teaching and classroom culture. Based on Hofstede's index values, researchers would expect teachers to have the sole authority in the classroom (high power distance), and that they highly encourage student collaboration in their classrooms (low individualism). However, other research studies from Tanzania such as [128,185] report communication is primarily teacher-dominated, and even when more time is allowed for lectures, the teachers generally talk for longer rather than incorporating collaborative practices such as group work. Students generally speak up only when called upon or instructed to do so, or to report conflicts with other students; when they initiated conversations unprompted, the teachers either ignored or silenced them. Stambach (1994) aptly names her paper based on a direct quote from a teacher, "Here in Africa, We Teach; Students Listen", to underscore this teaching culture. In our 2018 study [199], we found that while students sometimes collaborated when working with technology by themselves, they worked entirely independently in the presence of a teacher. The problem with relying on system-based theories is that they assume a monolithic culture even in countries such as Tanzania with a wide variety of languages and cultures. Also, research studies are conducted few and far between in remote areas that they may not account for changes that may have occurred over time.

Over the last two decades, several researchers have put forward proposals for frameworks intended to guide the incorporation of culture into the design of education technologies. Each of these frameworks privileges a particular theoretical perspective, which naturally results in making certain trade-offs between scalability and learner-fit to design appropriate technology solutions. Figure 34 shows five main frameworks for culturally aware education technologies, arranged with respect to the particular choices they make between these two factors. Theories such as Hofstede's system of values take the parameterization approach which involves identifying high-level factors on which cultures differ, assigning students to parameter values for different factors based on their demographic information (e.g., their home country), and presenting them with interfaces and learning content that match their expected cultural dispositions. However, insights from our 2018 study suggests that we need to follow an approach that prioritizes learner fit more than the parameterization framework to effectively design learning interventions for this population.

Our research study uses the "Multiple Cultural" framework approach as described by Lyn Henderson [72]. She argues for an "inverted curriculum approach" that designs "a topic from the minority's perspective" without harming the pedagogical and cognitive learning goals. This approach recognizes that while group preferences are deeply important for learning, specific cultural groups are also situated within a globally-connected world: multiple-culturalism is thus defined as "the condition in which various cultural groups are able to maintain their collective identity and membership in a macro society" [171]. Henderson suggests that instructional designers consider [158] fourteen pedagogical dimensions (Figure 35) and include instructional approaches from various points along each scale at appropriate times in the design of their learning systems.

Figure 26: Different Strategies for designing Culturally-Aware Education Technologies

Our research contributes to the Human-Computer Interaction, Learning Sciences, and ICT4D scientific communities; it specifically contributes the "Role of Instructor" literature among Reeves fourteen dimensions. We examine how teachers perceive and incorporate peer-peer collaboration in their teaching practice to design learning technologies that provide the most benefit for this demographic, especially since we rely on these teachers to deploy and integrate these technologies into their teaching practice. We investigate the following research questions:

- What are the socio-cultural ideologies that influence teachers' disposition towards peer-peer collaboration in rural Tanzania?
- How are peer-peer collaborative practices demonstrated (if at all) in rural Tanzanian classrooms?
- What are some peculiar struggles teachers and students experience in this learning context, and (how) can technology help?

6.2 Proposed Data Collection, Analysis and Evaluation

6.2.1 Teacher Interviews

Throughout the one-month period, I recruited and interviewed teachers about their expectations for collaborative behaviors in the classroom, and how education technologies could potentially improve their teaching practice (see Appendix B for interview script). I conducted semi-structured interviews with 24 primary school teachers and administrators. All interviews were conducted in Swahili with the help of a translator (who was born and raised in the village and was friendly with most of the teachers), except when the interviewee insisted on speaking English. The translator was asked to translate all questions and their responses – I asked follow-up questions when necessary. All interviews lasted about 45–60 min and included a brief demographic questionnaire. Teachers were compensated with the equivalent of a lunch meal voucher for their time. Consent was obtained from all teachers to interview them, and audio-record the interviews.

Overall, I interviewed teachers from four different primary schools – three government schools with Swahili instruction, and one private school with English Instruction. Each school was managed by teachers and four administrative positions. All school administrators also teach classrooms in addition to their administrative duties. Table 5 shows the different administrative positions in each school and their duties. Table 6 shows the number of students in each classroom across the different schools.

Position	Required Qualification	Duties
Head Teacher	Diploma	Leader of the school - all the other administrators report to the Head Teacher. Deploys all government intiatives and policies in schools.
Deputy	Certificate	Assistant to Head Teacher
Academic Master	Certificate	Manages all academic issues including exams, timetables, teachers schedules, lesson plans, lesson notes, orders textbooks, learning materials, student attendance etc
Assistant Academic Master	Certificate	Assistant to the Academic Master.

Table 4: School Administrative Positions and their Duties

	Number of Students per Classroom			
	Government 1	Government 2	Government 3	English Private
Nursery 1 (N1)	NA	NA	NA	24
Nursery 2 (N2)	126	65	180	24
Primary 1 (P1)	162	77	160	22
Primary 2 (P2)	142	85	210	20
Primary 3 (P3)	174	87	208	24
Primary 4 (P4)	151	61	150	22
Primary 5 (P5)	94	NA	77	23
Primary 6 (P6)	76	NA	81	31
Primary 7 (P7)	68	NA	45	12
Total Number of Students	993	375	1111	202
Number of Teachers in School	10	1	10	10
Teacher to Student Ratio	1:99	1:375	1:111	1:20

Table 5: Number of Students per Classroom across the different schools; The government schools only have one classroom for Kindergarten vs two in the private school. 'Government 2' is a new government school and highest class is currently Primary 4.

Interview topics included an open-ended description of the teacher's educational history and experience; their motivations for working in a rural area rather than an urban city; their experiences with collaborating with their peers in their early education across knowledge levels and gender, their current attitude towards peer-peer collaboration in the classroom, and their opinions on technology's usefulness and suggestions for incorporating technology into their teaching practice. Sample questions can be found in Appendix B. The native-speaker translator was also allowed to share their experience with collaboration and teaching during the interviews to increase camaraderie and the conversational format of the interview. Table 7 presents the demographic information and qualifications of the interviewees.

ID	Gender	Age	Teacher/Admin	Years of Teaching	Subject(s)	Classes Taught	School	Teaching Qualifications
2	F	20's	Teacher	7	Science, Math	P6 - 7	Govt 1	Certificate
3	M	30's	Teacher	5	English	P6	Govt 1	Certificate
4	M	30's	Teacher	10	All	P2	Govt 1	Certificate
5	F	50's	Teacher	28	All	Nursery	Govt 1	Certificate
6	M	26	Teacher	4	Math, Swahili	P1 and P5	English Private	Certificate
7	M	27	Teacher	3	Social Studies, Math, Geography	P3 - 7	English Private	Certificate
8	M	20's	Teacher	2	All	Nursery	English Private	Certificate
9	M	29	Teacher	2	Swahili, Science, Civics, Science	P2-P5	English Private	Diploma
10	F	21	Teacher	3 months	All	Nursery	English Private	Certificate
11	M	37	Head Teacher	10	Geography, English, Social Studies, Swahili	P3 - 7	Govt 2	Diploma
12	M	30	Teacher	6	Geography, Swahili, Science	P3-6	Govt 1	Certificate
13	M	56	Deputy Head Teacher	33	Math, Swahili	P4-5	Govt 1	Certificate
14	M	48	Academic Master	24	English, Social Studies, Swahili	P3 and 7	Govt 1	Certificate
15	F	27	Teacher	4	Swahili, Social Studies, Civics	P3-4	Govt 1	Certificate
16	M	30	Assistant Academic Master	4	Eng, History, Swahili	P 1-7	English Private	Bachelors
17	M	29	Deputy Head Teacher	6	Swahili, Science, Social Studies	P 4,6,7	Govt 3	Certificate
18	M	29	Academic Master	4	All	P1	Govt 3	Certificate
19	M	28	Teacher	4	Math, Science, Social Studies	P 4,5,7	Govt 3	Certificate
20	M	31	Teacher	7	Math, Science	P 3,4,6	Govt 1	Certificate
21	M	30	Teacher	4	Science, Math, Swahili	P 2,3,6,7	English Private	Certificate
22	M	27	Academic Master	4	Swahil, Math, Social Studies	P 4 - 7	English Private	Certificate
23	M	30	Head Teacher	7	Math, English, Science	All	English Private	
24	M	30	Deputy Head Teacher	5	Math, Science	P 1,2,6,7	English Private	Certificate

Table 6: Teacher Demographic Information

All interviews were audio-recorded and transcribed for analysis. Three members of the team reviewed all transcribed interviews, and identified emergent themes related to student collaboration and technology use following a grounded theory approach. All high level themes were triangulated with other types of data gathered during the study including debrief recordings, follow-up interviews, classroom observations, and photographs to ensure that all evidence were mutually supportive [119]. These interactions were aggregated in a shared working document and after all sessions were categorized, all members of the team reviewed the findings, discussed all areas of disagreement, and re-categorized findings where necessary. Table 7 shows the teachers demographic information for all the interviewees in our study.

6.2.2 Classroom Observations

For this dissertation, I also present insights gathered from 23 classroom sessions from the English Medium private school, and 16 classrooms sessions from one government school. I observed sessions from eight teachers from the English Instruction primary school, and three teachers from the 'Government 1' school. I observed different subjects including Mathematics, English and Swahili Language Instruction, and Science and Social Studies. I conducted these classroom observations to annotate all routine student interactions and default help-seeking behaviors in the presence of a teacher. I specifically wanted to annotate when students reached out to one another for help when assigned individual work in the presence of a teacher, and whether the teacher reprimanded or praised them for attempting to collaborate on individual work.

Given that each classroom has about 15 to 25 students in the English-Medium private school, I divided each classroom into three observation groups divided by 3 different areas of the classroom. Focusing on each group for 5 minutes at a time, I marked whenever a student in the group initiated an interaction with another student when assigned individual work by the teacher. I annotated each interaction with the teacher's reaction – positive, negative, ignored, or did not notice the students' interaction. I also qualitatively recorded how the teacher responded to any student interactions. An example of a student interaction observation was as follows:

Date/Time: Oct 27, 1:30 PM **Class:** N2 **Teacher:** Mr. Ahmed **Subject:** Math

Time	Student Name/ID	Teacher Reaction (P|N|D|I)	Notes
2:00 PM	Baraka M.	N	Teacher tells him to face his work
2:02 PM	Furaha G.	D	Teacher does not notice her talking; She keeps pulling Rehema until she gets help

where the P = positive reaction from teacher, N = negative reaction, I = teacher notices but ignores the interaction, and D= teacher does not notice the interaction.

I recognized that my position as an adult, observing students in their classrooms, may have led to their behaving unnaturally, therefore I took multiple steps to try to increase students' comfort and rapport with me. For every observation session in the English Private school, I sat at the back of the classroom and participated in all classroom activities just like students. Teachers often called on me to answer simple questions, to test my knowledge of Swahili, or to provide meaning and additional context to English words. Students often sang congratulatory songs when I got questions correctly, and laughed at ((and sometimes corrected) me when I got questions wrong. I conducted a treatment vs control experimental study on the same days as my classroom observations – each classroom was assigned a technology period daily, where I was allowed to take the students to conduct the experiments at a location that was a 10-minute walk from the students' classrooms. Every day, I walked with students from their classrooms to the experiment sessions, and they usually spent this time teaching me Swahili, and asking me questions about living in the US and my family. I also took the opportunity to ask them about some classroom behaviors that I did not understand. All these factors increased their comfort with me and allowed them to behave more naturally around me as I became a familiar but non-authority figure in the classroom space. As proof of their comfort around me, students often came to me to ask for answers to questions assigned by their teachers after unsuccessfully asking their friends for help when teachers left the classroom.

Given the large class sizes in the government schools, this observation protocol was impractical for the teaching sessions observed at the 'Government 1' school. Rather than focusing on the students, I qualitatively recorded details of the teachers' instructions, if and when they incorporated peer collaboration in their teaching practice, as well as any difficulties they faced teaching such a large classroom. All classroom observation notes were handwritten, and an audio recorder was used to capture teacher-student interaction and at my discretion. Permission was taken from the head teacher, the academic master, and the classroom teacher before I began all observation sessions. Students were also informed of my presence and were asked to welcome me to join their classrooms in both schools. At the end of each day, I reviewed all audio recordings, and discussed observation notes with a native speaker for translation into English when necessary as well as their insights on data gathered to provide additional context. Finally, I audio recorded all classroom observation notes, additional reflections and review meetings with the native speaker daily for future transcription and analysis.

Three members of the team reviewed all classroom observations, and identified emergent themes related to student collaboration and teaching practices following a grounded theory approach [43,119]. All the high level themes were triangulated with other types of data gathered during the study including debrief recordings, follow-up interviews, and photographs to ensure that all evidence were mutually supportive [119], and to generate a definitive list of themes for further analysis. These transcripts were analyzed using a Qualitative Data Analysis tool (Atlas Ti) to categorize the observation transcripts into the agreed upon themes to uncover all interactions related to student collaboration, collaborative teaching methods, and other classroom practices using a Thematic Analysis approach. Insights from data gathered from these classroom observations were used understand normal student-student, and teacher-student interactions and collaborative behavior in the classrooms.

6.3 Findings

6.3.1 RQ 1: What are the socio-cultural ideologies that influence teachers disposition towards peer-peer collaboration in rural Tanzania?

Government policies highly influence teachers' attitudes towards peer-peer collaboration

We asked teachers about their experiences with peer collaboration while growing up. All teachers except four shared that their teachers supported collaboration; they started supporting collaboration when they realized that students needed additional help from what they could provide or when their position as authority figures prevented the students from asking them questions.

> *When I was in primary school, teachers only wanted us to work by ourselves. When they realized that students were unable to understand, they started using group discussions to allow students share ideas.*
>
> Teacher 16.

> *Some families treat their children badly and it makes the children really stressed. So, when they come to school and they see teachers that remind them of their parents or uncles it makes them really sad. So they are more comfortable with working with students. Teacher to student communication is also very different because sometimes when the teacher is talking polite, the student can think they are being harsh... so some students prefer to listen to the ones who don't talk harsh.*
>
> Teacher 6.

The four teachers (teachers 5, 11, 13, 14) that did not have any experience with collaboration growing up all had above 10 years' experience and explicitly said the government did not permit their teachers to do that at the time.

> *They (teachers) did not allow us to cooperate when I was growing up. I went to school in the 80's ... at the time, the education policy does not allow students to cooperate. A teacher comes into the class and teaches students and all the students take notes. Right now, the education policy tells us to use the participation method.*
>
> Teacher 11.

> *No - my teachers did not allow us to collaborate. I am not sure of the reason why they did not support this – I think it was the policy that teachers had to do all the teaching in the school. I can remember only a few cases where collaboration happened... in the Kiswahili subject when students do not understand how to read and might ask other students to read so they hear... but it happened very rarely.*
>
> Teacher 14.

The interviewees whose teachers' supported collaboration stated that it was beneficial for students learning to include collaboration in the classroom, however, this collaboration was only allowed when purposefully designed by the teacher rather than naturally initiated by students. When students were caught collaborating outside of planned activities, they were often punished with being asked to prove their knowledge to the whole classroom, their seats were switched, or they were reprimanded with sticks. Teachers stated that collaboration activities usually took the form of discussions with other students at the beginning of a topic.

The influence that the government policies has over teachers practices in Tanzania cannot be underestimated. Teachers stated that a government job meant guaranteed income, medical and continued education benefits, as well as social security income after their retirement at sixty-five years old. One teacher mentioned that the government heavily subsidizes the cost of obtaining a teaching certificate with the expectation that teachers will work for the government schools in return. After teachers graduate, the government assigns them to teach in any part of the country that needs more teachers without their input. Teachers are aware of this and are happy to receive a government posting even if they were unhappy with the physical conditions of their place of assignment. When asked, all the government schoolteachers stated they would not leave the government teaching job for a private school even for double the salary and smaller class sizes. However, they acknowledged that education in the private school was of a higher quality than the government school due to the smaller class sizes – three government schoolteachers we interviewed sent their children to the private school for education. The private school teachers shared the same sentiment – 8/10 stated that they would leave their jobs for a government job even for half the salary and five times the number of students. The main reason stated was that their salaries in the private schools depended entirely on parents' ability to pay, and factors such as bad weather or planting seasons often determined whether or not they received their salaries unlike the guaranteed income at the government schools.

Teachers support peer collaboration but only when they design and scaffold the interactions

This experience with collaboration and the current government policy influenced teacher's current attitudes towards peer-peer collaboration in their classrooms. Most teachers interviewed (21/24) stated that they currently support classroom collaboration because students might be more comfortable around one another and teaching in large classrooms necessitates the use of group activities.

> *Yes because sometimes when teachers teach, students not understand them totally because of the many factors. Students fear them or other factors. But when students discuss with other students, they understand because they are used to each other, and the language they use is like the informal language. They use the vernacular languages so one can mix with another language to make the other student to understand.*
>
> Teacher 1.

> *Sometimes students do not understand teachers but they understand themselves so I support. In my experience, students in the same age group can be different in their understanding. Some students understand fast, others are slow learners. It is all about the IQ... some are high and others are low. Some cannot understand as fast as the teacher teaches. It takes time to serve these large classes…. My class has over 100 students. That is why sometimes students don't understand. Even with grouping the students, I do not serve all the groups in a day.*
>
> Teacher 5.

Teachers who did not support collaboration discussed their need to monitor students' individual knowledge, and that collaborative activities did not let them assess students individually. This need was expressed by teachers who supported collaboration – most (19/21) stated that they only allowed collaboration in an activity that was designed and coordinated by them. These teachers explicitly stated that they regarded it as cheating when students collaborated on individual work even if it was just a practice exercise and not a test/exam, and punished students using similar methods as their teachers.

When planning collaboration groups, teachers stated that they ensured that all group had a mix of both boys and girls as it was the government's policy to prevent gender segregation. All teachers and administrators (except the Head Teacher of the private school) also ensured that each group had a mix of students that they perceived as high achievers, and students who needed additional help. This grouping strategy was teachers' way of ensuring that that struggling students had someone to help them – the teachers often chose the high achieving students as the leaders of each group.

> *Sometimes I select the group leader, other times I allow the students select their group leader. The most important thing is that the leader of the group is bright.*
>
> Teacher 11.

While teachers perceived this grouping strategy to be effective for peer collaboration, they acknowledged that it may have negative psychological effects on the students who are struggling. In Chapter 7 of this document, we explored how this dynamic affects how students support one another while learning with technology.

> *No.... the less brilliant students are afraid of the brilliant students... they cannot help them with anything. [what about experiences like with herbs or animals or with money?] No.... [laughs]... It is not possible for the less brilliant students to teach anything because they are afraid of the brilliant students. Even if they know something, they cannot say it.*
>
> Teacher 11.

> *In academic issues, it is very difficult for this (struggling students to speak up) to happen because he is afraid of the brilliant students... he doesn't feel that he can say that this is correct or this is wrong for the brilliant students ... he just accepts whatever the brilliant students says… but in things like sports or environmental issues and other issues outside the class maybe it is possible.*
>
> Teacher 17.

We observed practices in the private school classrooms that may reinforce the apprehension that low achieving students feel regarding answering questions that they are unsure of. When students answered questions after being called upon by the teacher, their peers sang a 'shame' song if they answered a question incorrectly:

"Shame shame shame… shame upon you... a very big boy/girl."

or a song of praise if they answered questions correctly.

"Well done well done… try again another day... a very good boy/girl."

While we did not interview students on how the 'shame' song made them feel, it may partially explain their unwillingness to speak up in groups learning situations with higher achieving students present.

6.3.2. RQ 2: How are peer-peer collaborative practices demonstrated (if at all) in rural Tanzanian classrooms?

Teachers rarely incorporate collaborative activities in their teaching practice

Although most teachers stated that they support students working together, we observed only 6/39 sessions where teachers incorporated collaborative activities in their classroom practice. Two of those collaborative sessions occurred the day after we interviewed the teachers. Table 7 shows a description of the collaborative activities we observed.

Teacher ID	Grade	Description of Collaborative Activity
Teacher 5	Nursery	Lesson on primary colors. She divides the class into four groups and hands each group a different colored ball. She calls each group by their color name and asks them to perform a different motion e.g. jump, walk forward and backwards, dance etc. Sometimes she hands all colored balls to students within one group and asks them to perform the different motions, switching colors often, while the other students watch.
Teacher 5	Nursery	Similar color teaching activity as previously described.
Teacher 6	Primary 1	Lesson on the addition of two-digit numbers. He wrote a question on the chalk board: 43 + 24. He called four students to the front of the class – one student to draw three balls, the second to draw four balls, the third to count all the balls, and the fourth to write the answer in the digit form. Most students raised their hands for the chance to write on the board. He reviewed each problem after it was completely solved.
Teacher 6	Primary 3	(This occurred the day after I interviewed him). Lesson on representing word problems using pictograms. He started by sitting children in different mixed-gender groups. Then he wrote a question on the board with different students' names in one column and drew the corresponding number of flowers each student had in the adjacent column. He asked each group a different question e.g. "which student has the least?", "how many flowers do all the students have?" etc. Students in the groups he picked raised their hands, and he called on one student to respond. After this activity was over, he asked the students to return to their seats and he gave them a quiz at the end of the class.
Teacher 14	Primary 2	Lesson on words and their opposites. He invited a few students to the front of the classroom. He then asked the whole class, "what is the opposite of tall"? They all said "short". He asked the class to point to all the tall students in front, and all the short students as well. All the students participated, and they all enjoyed this activity. He invited other students from the class to suggest other words e.g. fast, hungry etc. and asked the students in front to act out the opposites.
Teacher 14	Primary 3	(This occurred the day after I interviewed them) Lesson on animals and their babies. He started by calling on students who are high achievers in his class and moving them to other tables in the class – he informed them that they are the group leaders. Then he held up his phone in front of class and played a downloaded YouTube video on baby animals. Students took notes as the video played. After the video stopped, he told students to write down all the animals and their babies from the video. Students started doing this work individually, but he told them to discuss with one another and come up with answers together. Students began talking to one another in whispers. Shortly after, he leaves the class and students started discussing loudly and moving around the classroom coming up with answers. After about five minutes, he returned to the class and they immediately returned to their seats. He called on each assigned group leader to present the work from their group.

Table 7: Description of group activities observed in the classrooms.

The teaching methods that were most commonly employed depended on the age group of students and the class size. Teachers in nursery classrooms commonly used songs, dance routines, and had their students repeat after them often. In the private school, there was a lot of individualized attention on students, and students were sometimes rewarded with small gifts e.g. pencils for answering tough questions individuall. Teachers often walked around the classroom inspecting student notebooks and correcting errors, ruling margins in their notebooks, holding students hands to teach them handwriting, and even helping them with obtaining writing materials. In the primary schools, teachers rarely used songs to teach, but employed mainly lecture-style instruction and rote repetition. Teachers routinely connected their content to contexts that students were familiar with. In a lesson about soil erosion, one teacher in the private school pointed to the road outside their classroom as an example, and called on students whose fathers were farmers to explain the concepts of over-grazing and cutting down trees to students. As expected, this sort of individualized attention was impossible in the government school with the large class sizes. Teachers mainly lectured for the entire class period, ending with a class exercise that they collected for grading after.

Students get reprimanded by teachers for collaborating with one another outside of planned group activities

Unlike elementary schools in the United States, teachers in Tanzania are not permanently assigned to a classroom i.e. there was no officially assigned teacher for each classroom. All teachers sat in a staff room and went to different classrooms when they had a subject to teach. It was common practice for teachers in both the private and government schools to assign students practice exercises at the end of their lecture. In the private school, teachers frequently left their class after they assigned activities and went back to the staff room, assigning one student the task of collecting all the notebooks and bringing it to the staff room for grading. In the government schools, teachers collected the notebook themselves and took it back to the staff room at the end of the period.

In the private school, students collaborated very openly with one another on practice exercises every time the teachers left their classroom. Students collaborated across age and gender, and across academic ability. They sometimes collaborated discretely while the teacher was still in the classroom but were reprimanded when the teacher caught them. Altogether, I recorded thirty-nine incidents of students reaching out to their peers for help in the presence of a teacher – twenty-four of those incidents went unnoticed by the teacher, twelve times the teacher noticed and reprimanded the students either by telling them to work alone or switching their seats, and there were three incidents where the teacher noticed but ignored the student. Students used different techniques to disguise their need to collaborate include pretending to borrow writing materials from their friends and whispering when the teacher had their back turned to them.

Teachers primary complaint against students collaborating on individual activities was that they assumed that students simply copied answers to practice questions from their peers. When asked about why he thought collaboration on individual exercises was bad, teacher 21 responded,

> *Cheating is bad. It means they don't understand it. That can make them to fail... if they copy you won't know who knows it.*

As the teachers suspected, I observed several incidents of students copying answers from their peers. However, contrary to teachers' beliefs, students collaborated in more ways than just asking their peers for answers. In the private school with English instruction, students sometimes did not understand the instructions of some class exercises that they were given. I observed two instances where students went to their friends to ask for help translating the questions into Swahili so they could answer it on their own. Students very often worked on problems on their own but verified their answers with their peers before turning in their notebooks for grading. This behavior of confirming answers before submission was more common among students who were the high achievers in the classroom irrespective of gender. There were two instances where high achieving students reported their lower achieving peers to me for trying to copy their answers; however, they had no complaints when their higher achieving peers engaged in the same behaviors. Finally, of the thirty-nine instances of collaboration, twelve of them involved students discussing questions, and reading their notebooks together while searching for answers to practice questions.

6.3.3. RQ 3: What are some peculiar struggles teachers and students experience in this learning context?

Large classes are problematic

One of the major issues reported from previous studies about public education in Tanzania is that there are very large number of students with few teachers to support them. This study is no exception – the teacher to student ratio in the government schools in our study ranged from 1:99 to one school having only one teacher to support over three hundred students. Combining these large class sizes with working in villages with limited resources and a higher number of struggling families, teachers have learned to accept that they cannot possibly support all students in their classroom, and spend a lot of time on non-teaching activities at the expense of their lecture time.

In one class session observed, a government schoolteacher was giving a lecture about parts of the body to primary one students. He asked the students to draw a stick figure in their notebooks and come up to him for grading before he began the lecture. It took the teacher the entire class period to grade the stick figure of the over 150 students present in the class that day – he never got to the main lecture before he had to leave. Several students did not have writing materials and he had to help them find extra pencils in and out of the classroom to allow them to participate in the classroom activity. In another class observation, the teacher was instructing the students to say numbers greater than one hundred. She called each number and the students repeated after her. She noticed that only the students in front were paying attention and responding. Those at the back either mumbled responses or were completely silent and she simply ignored them and focused on the students in front.

Infrastructural challenges in rural areas

After discussing the topic of peer-peer collaboration with teachers, we posed a hypothetical question to USD: “If I offered you 100 million Tanzanian Shillings to improve education in this village, what are the top 5 things that you would spend the money on?” All teachers mentioned building more classrooms as the most pressing need in their school. Other items frequently mentioned included electricity in schools, food for students, housing for teachers and sufficient learning materials including textbooks and writing materials for students. We asked teachers this question after presenting them with a demo of our learning system, of which they all said it would be beneficial for their teaching practice. When I pressed harder about why technology was not on their priority list some teachers adjusted their list to include technology among their teaching materials, while others admitted that their schools had more pressing needs.

Teachers all agreed that education technologies could help alleviate some of the problems they experience with teaching in rural areas. Teachers in the government schools discussed that technology can help to automate grading and allow them more time teaching time. Others said technology could help them ensure that all students had some form of instruction in large classes or when teachers were unavailable to teach. When I pressed on how they would deploy educational technology, assuming unlimited resources, they all mentioned that it would be impractical to deploy these technologies one on one with students.

> *Even if we have the tablets for free, there will be a problem with noise. Everyone will open a different program and you can't control it.*
>
> Teacher 15.

> *The number of students in large classes will make this really hard to manage. I prefer the use of projectors. When there is one tablet per student, I am not really sure of how to use the technology… it means that I have to figure out a way to monitor all of them. I will be giving a lecture in the class and students are just clicking away.... [*thinks for a while*]… I can't really see a way to use this if all students have it one by one.*
>
> Teacher 14.

Teachers said they could address these class size challenges by only giving one tablet to a group of students, or dividing the class into smaller groups and only using technology one group at a time. They also mentioned that the novelty of technology will prompt students to be more punctual at school. Teacher 5 compared the novelty of education technologies to a reading intervention that a teacher recently created at the school:

> *Like the primary 2 teacher, he has created like a machine for reading. So when he holds it up, it falls out like 'ba bi be bu' so all the students can be surprised and read what comes out. No student is missing the class because they want to see the machine work. It is the same with the computer – all students will come to school because of the technology.*

Finally, teachers discussed the potential of education technologies to better prepare their students for an increasingly globalized world and help students with a better understanding of the subjects they currently teach. All schools that our interview participants worked for had an Information and Communications Technology (ICT) subject as part of the school curriculum. However, teachers had resorted to only showing student pictures of computers and other technologies, admitting that students do not have a full understanding of how such systems work.

> *With the technology in this time of globalization, in a few years, they will need to know how to use these technologies to get employment, so we have to teach them. Even the materials we teach now, like if you are the ICT teacher, we can teach them practically instead of just theoretically.*
>
> Teacher 3.

> *For the older students, there is a subject in primary 6 and 7 where the children are supposed to learn how to use technology. Teachers are supposed to teach students about laptop and desktop and show the students but they don't have them so they teach theoretically. Technology will be helpful for those. In science, there is the topic of the nervous system where it wants the students*

to look deeply into the nervous system. Unfortunately, they don't have those materials or even the pictures in the books so the technology will help show the children pictures of things they can't see…. There was another subject [taught in the school] called broadcasting and communication that failed because there were no materials to teach the students. Technology can help. It was about technology and phones and other communicative devices, but they had no way to demonstrate to the children and therefore stopped the class.

Teacher 14.

6.4 Implications for Design

Our research provides additional nuance from previous studies that although teachers do not routinely incorporate collaborative activities in their teaching, they believe that peer collaboration leads to improved learning for students, and will likely be welcoming to curriculum changes that help **them** create and manage collaborative activities better. We show that teachers do not typically support unstructured peer collaboration (as predicted by Hofstede's values), neither are they opposed to the idea of students teaching one another when properly scaffolded (as implied by previous research studies like e.g. Stambach, 1994). This insight allows researchers and educational practitioners the opportunity to introduce teachers in rural classrooms to practices and teaching methods that allow them to retain their authority in the classroom, while enjoying the benefits of peer collaboration. Our study also shows that it is critical to at least understand government and national education policies in a country like Tanzania before introducing any educational interventions. With the job security and benefits of a government jobs in Tanzania, teachers in rural areas are likely to continue seeking after the financial stability of teaching in government schools with large class sizes and limited resources rather than the financial uncertainty of teaching in private schools even with much more ideal teaching conditions. Researchers should focus on designing interventions suitable for managing very large classroom sizes with limited manpower to manage those interventions.

In Tanzania specifically, there are educational policies that disproportionately affect under-privileged students which technology can help overcome. First, the language of instruction in Tanzanian primary schools is Swahili, however, students must be educated in English in secondary schools. As a result, there is a massive attrition from students who make it into secondary schools but cannot cope with the language differences [170]. During these interviews, only three of twenty-four teachers were fluent enough in English to conduct the interview without a translator despite completing at least six years of education in English. Also, there are high stakes, one chance, examinations even for young students in Tanzania that if failed, prevent them from continuing their education. As shown in table 5, there is a noticeable drop-off in the class sizes after primary 4 in 'Government 1' and 'Government 3' schools. There is a national examination that students have to take in primary 4 that they have only one chance to pass otherwise, they cannot be promoted to primary 5. There is also a similar national exam at the end of primary 7 which determines if students can attend secondary school, and another at the fourth year of secondary school which determines if students can attend university for professional degrees. Finally, prior studies have reported incidents of frequent teacher absences in Tanzanian primary schools [97]. Teachers in our interview provided some context for this issue noting that they are often called to the government district office for training, and that they assist in nation-wide government-run initiatives such as elections and the census. Education technologies can play a critical role in filling some of these gaps including helping student and teachers alike improve their English language skills, it can serve as a resource to help prepare students for critical national examinations and can provide substitute instruction for students when teachers are absent.

As highlighted in the findings section of this chapter, teachers do not think it is feasible to manage their classrooms if all students are given technology one on one. In addition to it being very difficult for teachers to scaffold students' use of the technology, the noise generated from those devices alone would make it impossible for students to hear any instructions. Of course, it is possible to use headphones to circumvent the noise issue, however, that is additional equipment that would need to be secured and maintained for proper use. Therefore, this opens the opportunity to challenge the conventional design paradigms of personalized intelligent tutoring systems to adapt for use by multiple students while still maintaining the learning benefits of those devices. There is also room for making advancements in technologies suitable for teaching large classes such as projectors, low-power clickers for multiple choice quizzes, technologies that help support teachers tasks such as grading, multimedia content to supplement or substitute traditional textbooks which are scarce in rural areas etc. This is not to say that popular models of deploying educational technologies one on one with students in classrooms will not work in this context. However, without major modifications, one on one technologies might be more suitable for schools with smaller class sizes or after school learning centers with fewer number of students.

Despite the potential of educational technologies making a positive difference in these classrooms, it is important that researchers understand that these communities face unique challenges that may hinder the adoption or deployment of even the most effective technologies. Technology interventions require manpower to ensure that devices remain charged, updated, and safe. Despite the best intensions of schoolteachers and administrators, most schools in rural villages do not even have enough classrooms for students to sit in for their regular lectures – they also lack basic infrastructure such as desks and chairs for students. Therefore, it is often impossible to secure the physical space for technology-based education. None of the government schools in our study had electricity; the fastest mobile internet download speeds ranged from 120Kbps to 384Kbps. Without a dedicated Wi-Fi connection or guaranteed power, charging or updating technological devices may be impossible.

As evidenced in the teacher to student ratios in our study, there is already a shortage of teachers to teach students even the most basic subjects. Even though technology has the potential of making the teaching of those basic subjects more effective, it might be difficult to convince school administrators to dedicate these already scarce resources to new initiatives rather than traditional teaching methods that they perceive to be highly effective. Teachers time are already stretched thin with not only worrying about educating students but also helping to ensure that students are fed, that they have basic supplies such as books and uniforms, clean water, and providing a relaxing environment for students who may have stressful chores to manage at home such as farming, cooking etc. To manage our research efforts over the last few years, our research team hired a staff member who was responsible for charging, securing, and liaising with other members of the team to ensure proper management of the efforts. Due to space constraints and security issues, the tablets had to be transported daily from the staff's home to the schools daily. This limited the number of tablets that the staff member could physically carry to the schools to 12 tablets per day. While this number was sufficient in small classes of 20-24 students, it was not sufficient to serve large classes of over 100 students, requiring more dedicated resources to store and manage the devices. Researchers must think very critically about the feasibility of educational interventions given some of these limitations highlighted. For most government schools in rural Tanzanian villages, researchers likely have to fund many additional costs e.g. staff compensation, technological devices, physical spaces and furniture, internet costs, security of devices etc. to successfully deploy even the most basic interventions.

Chapter 7 – Help-Seeking System Intervention for Primary Schools in rural Tanzania

7.1 Overview

In my prior work, I conducted two studies in Tanzanian rural villages to understand how children support each other while learning with education technologies. In the first study, I deployed a tablet-based learning system to children without prior technology exposure in different social contexts. I found that there are three main kinds of support that students in this socio-cultural context need – digital literacy support, application support, and domain knowledge support. Teachers were able to offer all three kinds of support to children, and peers offered digital literacy and application support primarily by modeling correct behaviors. I also found that in the presence of a teacher, peers did not communicate with each other, preventing any possible collaboration, as such behavior is often mistaken for cheating. Finally, I found many instances where students simply did not touch the tablets if they were unsure of what to do (or did not think they had permission to touch the device). As a result of these findings, the final part of my dissertation study investigates the use of a help-seeking system that automatically detects when a student needs any of these three kinds of support, as well as student hesitation, and redirects them to a knowledgeable peer to assist them in the absence of a teacher.

Following my initial study, I conducted an experiment to investigate whether students in this cultural context, with proper training, could naturally take up the role of supporting their peers. I trained student group leaders to provide adequate application and digital literacy support for their peers, varied the experimental conditions by informing some groups of the presence of their group leader, and directed students to reach out to them if they needed any help. The other groups were not informed of the leader's presence; however, all leaders were informed before every session that it was their responsibility to support their peers during the experimental sessions. I found that in groups where knowledge of the leader was not made public, the leader provided support similar to the other members of the group, interacting almost entirely with their adjacent peers. For groups where the knowledge of the leader was made public, peers frequently asked them for help for themselves and other peers, and leaders persisted for much longer through helping their peers with difficult problems. When leaders in this public condition were unable to help after a long period of trying, they left the experiment session to find a knowledgeable adult to provide the help their peers needed. I also found that students wanted to maintain the agency of asking for help at their discretion, often refusing help from leaders who provided unsolicited assistance.

This dependence on one student to provide support for the entire group placed undue pressure on the leader, often distracting them from their own tablets. This help-seeking model was similar to students' experience in the classrooms where they depended entirely on the teacher for help – the job of the teacher had just been transferred to the group leader. This newfound power also caused the leader to embody other frequently observed teacher behaviors such as reprimanding and even hitting their peers who distracted the entire group. My follow-up experiment demonstrated that in this context, it was the public awareness of the presence of a helper, and the social pressure associated, that caused peers to provide support for one another in classroom settings.

To complete this thesis, I deployed a help-seeking system intervention in an experimental study to support students learning with technology in school contexts. The system detected when students were specifically struggling with application, digital literacy, and domain knowledge issues, and made suggestions for them to seek help from an appropriate peer. All students were informed in the presence of their peers that they were all helpers and responsible for the group and were encouraged to support their peers if asked. This intervention enabled constant error monitoring, allowing students the opportunity to undergo productive struggle before stepping in, and gave students the autonomy to request help as needed; all system help-seeking interventions were suggestive so students could choose to ignore them if they pleased. Given that the suggested helper varied based on the task, this aims to achieve a more equitable environment as every student in a group can attain the position of a helper in a very short period of time.

This system was built following an Intelligent Novice Model, where it did not intervene with student activity as soon as an error is detected. Rather, the system was designed so students met a desired model of performance, combining both immediate and delayed interventions at different times depending on the problems detected. In some cases, the system provided support for students even before a task began – to reduce student application errors, students were shown a video showing them how to navigate each application along with its features the first time they encountered it. For tasks that required immediate feedback e.g. question level errors, the system provided some basic suggestions when students entered wrong answers to questions to support their domain knowledge needs.

When students needed more support that those provided initially, the system intervened after a certain amount of time had elapsed and recommended that they seek out a peer to support them. This enabled students to practice their generative skills such as resolving activity specific errors on tasks that needed more immediate feedback, and practice evaluative skills such as mastering different knowledge components from tasks that they may be able to recover from unassisted. In my previous studies, I had very limited observations of students providing knowledge-telling domain knowledge support to their peers, therefore, the experimental study was designed so that students were instructed to teach their peers, when they were asked for help. Although students had not demonstrated the ability to provide knowledge-building support in our previous studies, explicitly asking them to teach their peers, modeling after their teachers' behaviors, may elicit better helping-giving behaviors than our previous studies. Data for the experimental study was collected via video capture of all the experiment sessions and logs data from the tablet, teacher-student observations were collected in their normal classroom environment, and interviews were conducted in schools with teachers and school administrators.

For this study, I investigated the following research question:

- How do help seeking applications affect student learning, system engagement, and student interactions in rural Tanzanian classrooms?

7.2 System Design

Student errors were broadly categorized into two kinds of errors: Application Support, and Domain Knowledge Support (or both). Figure 28 shows a flow diagram of the different error types and the system intervention.

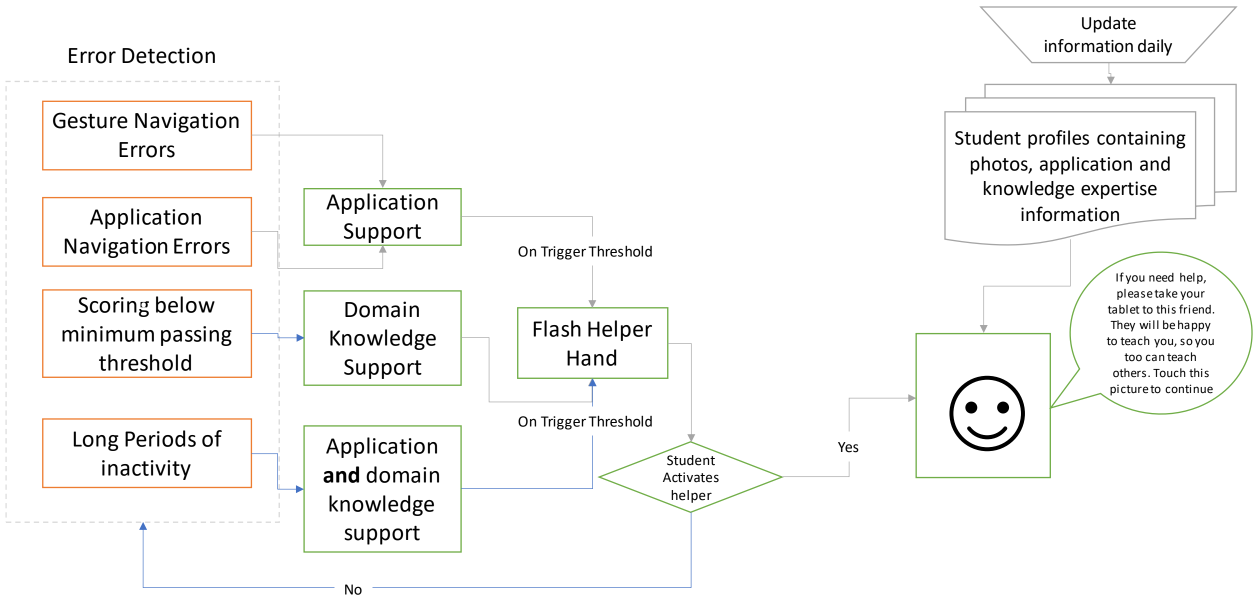

Figure 27: Error Detection and Intervention Flow Diagram for System Intervention

After students heard the intervention message the first time, the subsequent intervention messages were shortened to keep students engaged. The intervention ran constantly in the background while the learning system was in use. The intervention was designed to monitor and detect the following student needs

1. **Application Support:** This was triggered when students did not interact with applications correctly e.g. a student is required to tap but they are trying to interact with the tablet by dragging/swiping, or a they are trying to trace a character but not tracing in the writing area. Students may have enough basic digital literacy skills to generally interact with the tablet but may not understand how to correctly navigate a particular learning application. The system recommended a student who had successfully navigated that application before (or another application with similar mechanics). Students heard the following message on the system intervention, "if you need help with this activity, take your tablet to this friend…. they will be happy to teach you so you can teach others... touch this picture to continue". On subsequent notifications of a similar error, students heard, "take your tablet to this friend for help with this activity", and then "go to this friend for help".

2. **Digital Literacy Support**: This was triggered when student demonstrated that they did not yet have adequate digital literacy skills to interact with a learning device such as a smartphone or tablet e.g. students do not know that the right way to interact with a tablet is to tap on it with a single finger, and may perform other gestures like rubbing or trying to move objects on the screen with their palms. The scaffolding required for this kind of error was similar to the "Application Support" error as well.

3. **Domain Knowledge Support**: This was triggered when students did not have enough domain knowledge to achieve mastery in an activity. Currently, the system adjusts students' activity levels

based on their performance to ensure that they are placed in cognitively appropriate activities. Therefore, we expected to detect much fewer occurrences of this error type compared to the application level issues. This system intervention augmented activity level adjustment by redirecting students to their peers who have mastered the required knowledge components for collaboration and assistance while also adjusting their activity levels to others that may be more cognitively appropriate. Students heard the following message on the system intervention, “if you need help solving this problem, take your tablet to this friend…. they will be happy to teach you so you can teach others... touch this picture to continue”. On subsequent notifications of a similar error, students will hear, “take your tablet to this friend for help with this problem”, and then “go to this friend for help”.

4. **Hesitation:** This was triggered when students refused to interact with the learning device after an activity had begun. This might have been as a result of the student not knowing how to navigate an application (“Application Support” error), not having enough domain knowledge to attempt an activity (“Domain Knowledge” error), or simply being bored. The system recommended a student who had both the domain knowledge, and the application literacy for support after an acceptable time of inactivity has passed.

Both “Digital Literacy Support” and “Application Support” required that a gesture recognition algorithm was constantly running in the background. This was implemented using the Android GestureDetector library (https://developer.android.com/reference/android/view/GestureDetector). This library provides native support for detecting the following gestures: tap, double tap, long press, fling (or swipe), and a customizable motion listener.

7.2.1 System Implementation and Error Detection Criteria

As described in the section above, the four errors described above were categorized as either an application intervention error (requiring gesture detection) or a domain knowledge error (requiring performance tracking and activity monitoring) or both. Given that our system had been deployed with over 300 children in rural Tanzania for more than a year [198], I had a baseline representation of the average amount of time it takes a student to attempt to answer a question for all activities in the system. All initial activity attempt timing estimates can be found here. Based on these estimates, and the maximum number of attempts per question, student performance, and the student’s activity overall, the system chose the time to intervene with a help-seeking suggestion. Below, I described all the error types, their triggers, intervention types, and how rules for resetting the error listener.

1. Application Support:
   - **Definition**: Student is performing a correct gesture but not on the right target
   - **Trigger**: Student takes longer than time t to tap a valid target; t = average response time for the activity * the maximum number of allowable attempts per question. E.g. if it takes the average student 6 seconds to answer a question in the bubble pop application, and the application allows for 3 attempts per question, the system will intervene after 18 seconds of continuous struggle. This timing threshold was above the 90^{th} percentile of student question response times (based on historical data) for at least 70% of all the learning activities in the system.

- **Intervention**: Flash helper hand after time expires; if student clicks helper hand, system shows them a student's picture who has successfully navigated the application in the past in the same group, and suggests that they ask the student for help.
- **Reset**: Intervention recommendation will be switched off and monitoring restarted if a student taps a valid target (regardless of correctness) or new problem encountered
- **Demo**: See system demo here

2. Digital Literacy Support:
   - **Definition**: Student is performing incorrect gesture in an application. Robotutor is specifically designed for a low-digital literacy demographic so all applications rely on the 'tap' gesture, except the writing applications (tap + scroll), and the reading applications (tap + speech detection).
   - **Trigger**: Student continuously performs wrong gesture for a duration > time t; t = average response time for the activity * the maximum number of allowable attempts per question. E.g. if it takes the average student 6 seconds to answer a question in bubble pop, and the application allows for 3 attempts per question, the system will intervene after 18 seconds of continuously detecting a wrong gesture. This timing threshold was above the 90^{th} percentile of student question response times (based on historical data) for at least 70% of all the learning activities in the system.
   - **Intervention**: Flash helper hand after time expires; if student clicks helper hand, system shows them a student's picture who has successfully navigated the application in the past in the same group and suggests that they ask the student for help.
   - **Reset**: Intervention recommendation will be switched off and monitoring restarted if correct gesture is detected or new problem encountered
   - **Demo**: See system demo here
3. Domain Knowledge Support:
   - **Definition**: Student cannot answer enough questions correctly to pass the activity.
   - **Trigger**: Student has failed enough questions, will not meet minimum passing threshold, and will be demoted to an easier activity e.g. if passing threshold is 70% in a bubble pop activity spread across 30 attempts (3 attempts each for 10 questions), the system intervenes when a student fails 9 attempts.
   - **Intervention**: Flash helper hand after time expires; if student clicks helper hand, system shows them a student's picture who has successfully mastered that topic in the past in the same group and suggests that they ask the student for help.
   - **Reset**: Intervention recommendation will be switched off and monitoring restarted if student goes to a new activity.
   - **Demo**: See system demo here
4. Hesitation:
   - **Definition**: Student does not touch the tablet after a question is presented
   - **Trigger**: Student takes longer than time t to perform any gestures; t = average response time for the activity * the maximum number of allowable attempts per question. E.g. if it takes the average student 6 seconds to answer a question in bubble pop, and the application allows for 3 attempts per question, the system will intervene after 18 seconds of inactivity. This timing threshold is

above the 90th percentile of student question response times for at least 70% of all the learning activities in the system.

- **Intervention**: Flash helper hand after time expires; if student clicks helper hand, system shows hem a student's picture who successfully navigated the application and has adequate domain knowledge in the same group, and suggests that they ask the student for help.
- **Reset**: Intervention recommendation will be switched off and monitoring restarted if student performs any gesture within a given timeframe.
- **Demo**: See system demo here

Figure 29 shows an example of the helper hand activated, and the intervention triggered.

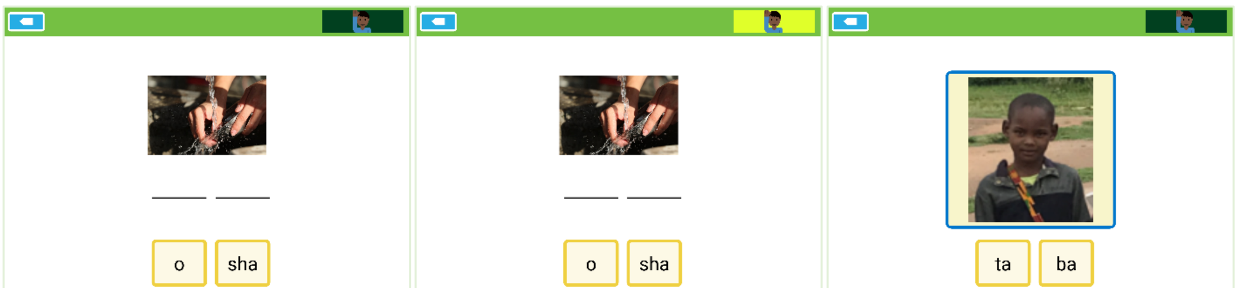

Figure 28: (L-R) Example of normal activity, help-seeking alert, and proposed intervention

7.3 Proposed Data Collection, Analysis and Evaluation

7.3.1 Proposed Study Design

I conducted a between subjects, repeated measures experimental study with 98 (Girls = 50; Boys = 48) primary school students ages 5 – 10 in a rural village in Tanzania. The students were distributed across 5 grades - Nursery 1, Nursery 2, Primary 1, Primary 2, and Primary 3. Most of these students had prior exposure to the learning technology, except for the children in Nursery 1 and Primary 3. Each experimental session lasted about 1 hour. There were 9 groups in each condition comprised of 5-6 students each, allowing for all students to have at least one non-adjacent peer.

Since student prior relationships are an important factor to consider in any intervention that involves student interactions, these groups were created to account for existing friendships within each classroom. Prior research studies on group learning and motivation show that performance is linked to increased diversity peer relationships, gender and age differences, and personality traits [9,27,144,176,179]. A technique called Sociometry was used to determine the "inter-relationships within a group. Its purpose is to discover group structure: i.e., the basic "network" of friendship patterns and sub-group organization" [174]. The formula below is used to calculate the cohesion coefficient of each group:

$$C = \frac{Mq}{Up}$$

$$C = \text{the coefficient of cohesion.}$$

$$M = \text{the total number of mutual positive choices made by the students.}$$

$$U = \text{the number of unreciprocated positive choices}$$

$$(\text{the total number of positive choices minus the number of mutual choices } (M).$$

$$p = \frac{d}{(N-1)}$$

$$where\ d\ is\ the\ number\ of\ positive\ choices\ allowed,$$
$$and\ N\ is\ the\ number\ of\ students\ completing\ the\ survey.$$

$$q = 1 - p$$

Prior to the first day of the study, each student was presented with a list (with pictures) of all the students in their classroom and were asked to identify the students they liked to play with. After this data was collected, randomized groups of 5-6 students were created to ensure that each group had an equivalent cohesion score. Figures 30-34 shows the friendship network map of all the students in each class, and how the randomized groups were created. In all grades, girls only selected other girls as their friends, and boys did the same as well. There were no grades with cross gender friendships indicated by the students.

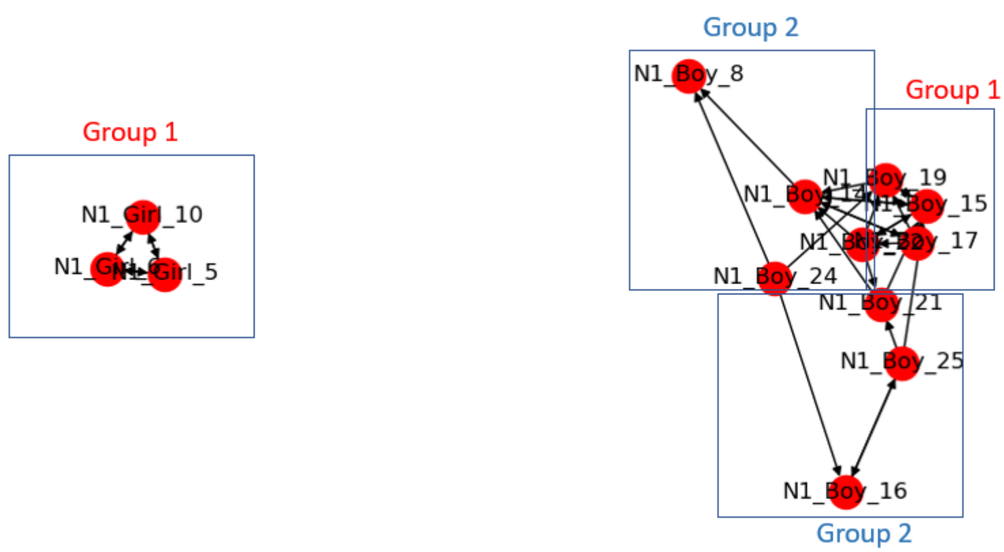

Figure 29: Nursery 1 Friendship Networks and Experiment Groupings

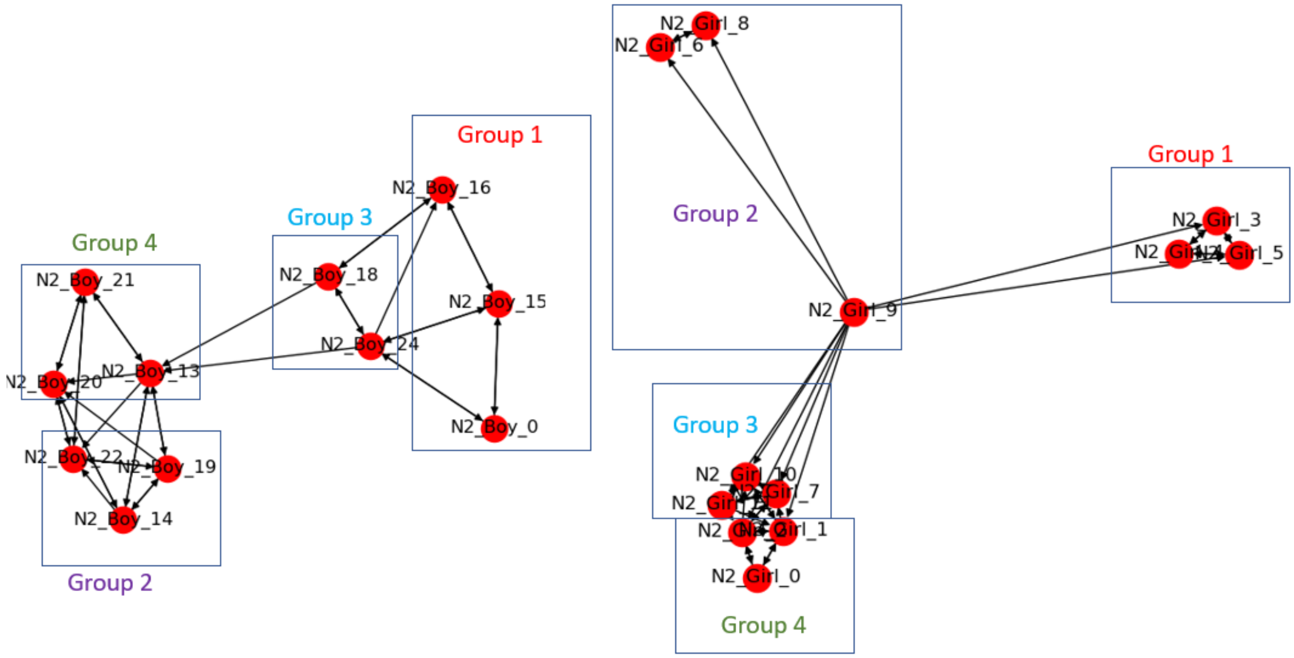

Figure 30: Nursery 2 Friendship Networks and Experiment Groupings

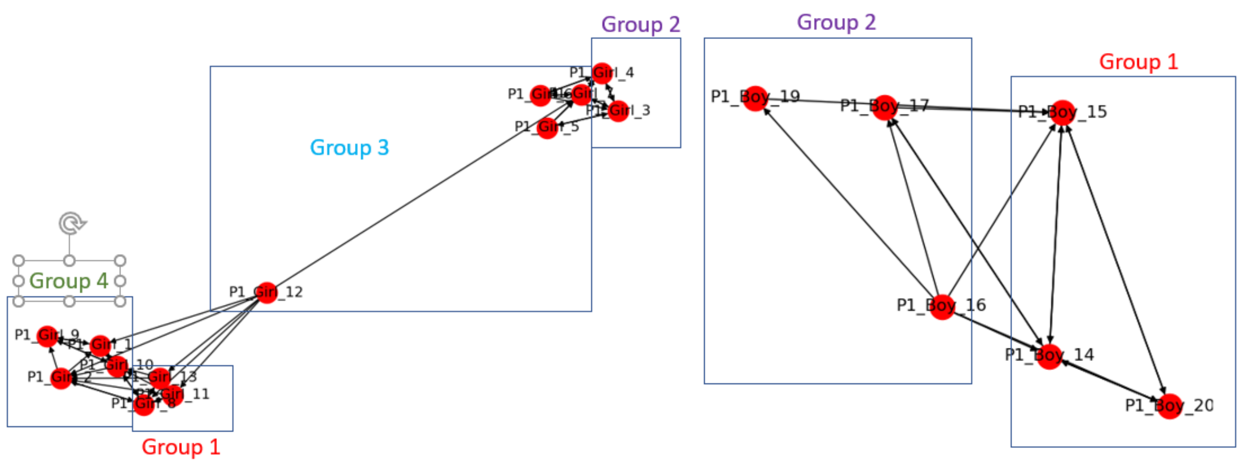

Figure 31: Primary 1 Friendship Networks and Experiment Groupings

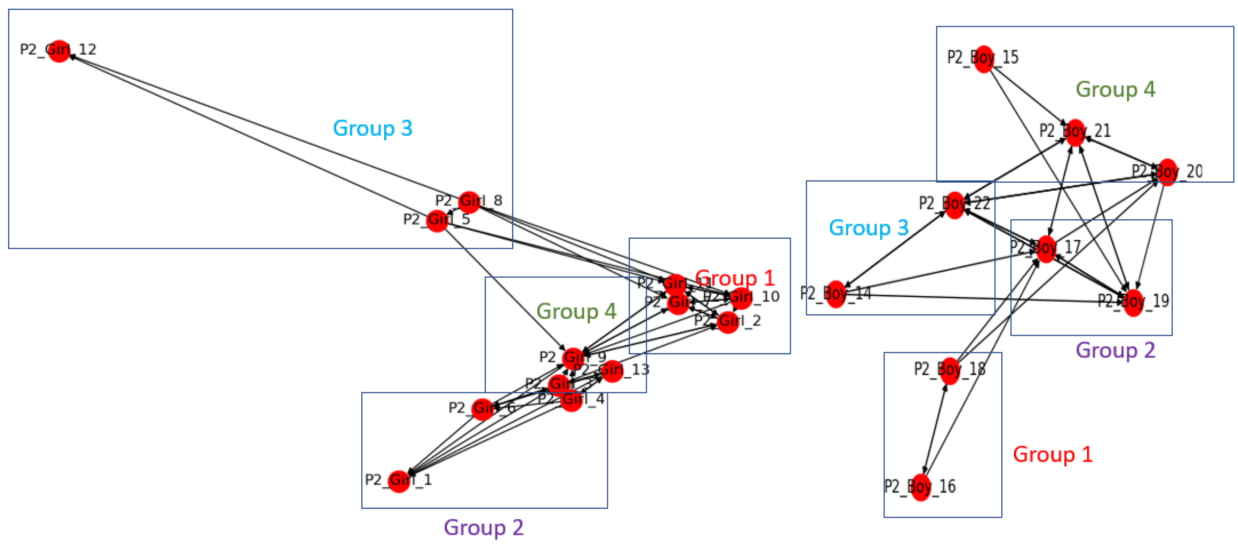

Figure 32: Primary 2 Friendship Networks and Experiment Groupings

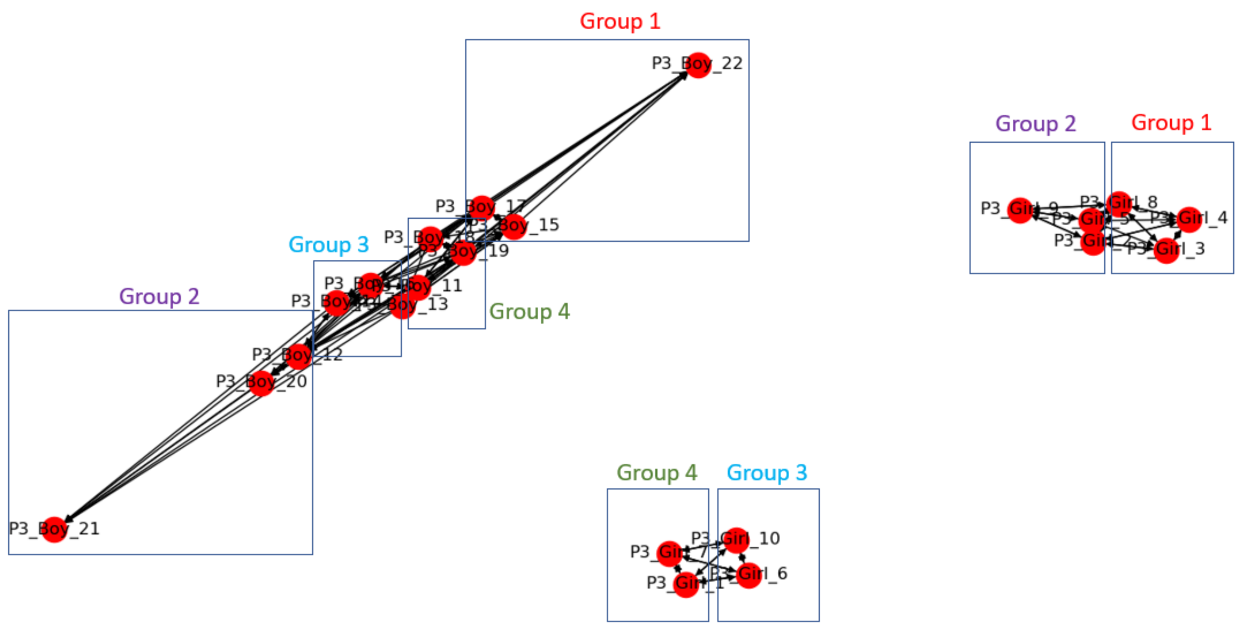

Figure 33: Primary 3 Friendship Networks and Experiment Groupings

After equivalent groups are created, groups were randomly assigned into treatment vs-controlled conditions. For the Nursery school students, there were 3 experimental and 3 control groups; for the primary schools, there were 4 groups under each experimental condition. Each group was observed on 8 different experimental sessions throughout the study – including 1 baseline and 1 final session without the help-seeking system enabled. This allowed me to gather insights on the students' interactions patterns without the help-seeking system, and how their behavior patterns would change if the system was suddenly taken away from them.

As this was an experimental study, the first few days were dedicated to preparing for the experiment. The study activities were structured as follows:

Prior to study:

- Obtained study permission from the school authorities, and village council.
- Distributed consent forms (see Appendix A) to all students and their families.
- Took student pictures, gathered data on student relationships with their peers in the classroom, and formed experiment groups.
- Administered pre-test to determine students' prior knowledge. (see Appendix C)
- Conducted pilot studies both in the US and in Tanzania with children in similar age groups
- Conducted an unsupported (without system intervention) baseline technology learning session so all students had basic familiarity with the tablet and learning system. This allowed for the configuration of students who could provide specific support for the different applications, and/or basic digital literacy skills.

Day 1 and 2:

- Conducted an unsupported (without system intervention) baseline technology learning session. This allowed me to observe baseline student behavior without the system intervention.

Day 3:

- Configured the system with baseline student profiles, including the kinds of applications that peers could provide support for when the experiment sessions began.

Day 4 – N:

- Pulled students from their home rooms to attend the study sessions in classrooms set up specifically for the experiment. For each study session, students were seated similar to the structure outlined in Figure 35, adjacent to one another, and their seating positions were randomized in each experiment session. At the end of each day, the helper list was updated (using an offline script) based on students' interaction and performance. We also observed as many classroom sessions as possible throughout the one-month period.

After the study:

- Conducted a post-experiment paper test for all participants.

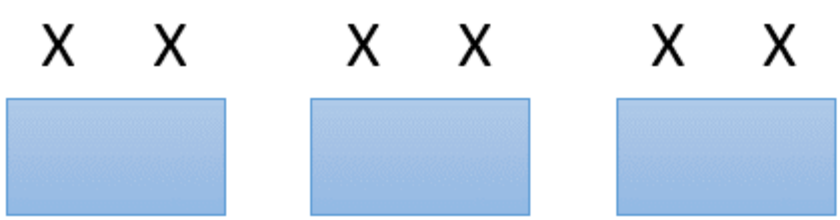

Figure 34: Students seating arrangement during experimental study

Table 8 shows basic demographics summaries and pretest scores for each group in our study. Each test covered basic numeracy, and literacy topics from Nursery to Class 3.

				MATH PRETEST SCORE		LIT PRETEST SCORE	
CLASS	GROUP ID	GENDER MIX	AVG AGE	AVG SCORE (max 38)	SD	AVG SCORE (max 21)	SD
NURSERY 1	N1_Control_1	6 Boys	5.2	6.83	2.23	1.00	1.10
	N1_Treatment_1	3 Boys, 3 Girls	5.7	11.14	3.63	3.43	2.51
NURSERY 2	N2_Control_1	3 Boys, 3 Girls	5.5	22.00	3.39	12.20	4.92
	N2_Control_2	3 Boys, 3 Girls	6.5	20.33	2.66	17.17	3.60
	N2_Treatment_1	3 Boys, 3 Girls	6.2	21.50	2.43	18.50	2.59
	N2_Treatment_2	4 Boys, 2 Girls	5.7	18.20	6.76	11.80	4.71
CLASS 1	C1_Control_1	2 Boys, 3 Girls	6.8	25.67	5.03	20.67	0.58
	C1_Control_2	5 Boys	7.4	25.20	4.66	20.60	0.55
	C1_Treatment_1	3 Boys, 2 Girls	7.0	27.60	2.97	19.80	2.68
	C1_Treatment_2	2 Boys, 3 Girls	8.4	32.00	1.00	21.00	0.00
CLASS 2	C2_Control_1	2 Boys, 3 Girls	9.4	30.25	2.87	20.75	0.50
	C2_Control_2	3 Boys, 3 Girls	9.3	27.00	4.00	20.67	0.58
	C2_Treatment_1	2 Boys, 4 Girls	8.5	28.00	4.64	17.60	4.22
	C2_Treatment_2	2 Boys, 3 Girls	8.6	28.50	2.65	20.75	0.50
CLASS 3	C3_Control_1	3 Boys, 3 Girls	10.0	31.80	2.49	20.20	1.30
	C3_Control_2	2 Boys, 2 Girls	10.8	33.67	2.08	20.33	1.15
	C3_Treatment_1	3 Boys, 3 Girls	9.2	36.25	2.06	21.00	0.00
	C3_Treatment_2	3 Boys, 2 Girls	9.8	35.00	1.00	20.67	0.58

Table 8: Pretest scores and demographic information for experiment groups

We gave the experimental groups tablets with the help-seeking intervention enabled, and the control groups received tablets with just the learning system. There were no adults present in the experimental sessions. At the beginning of every session, we read the following script to the children (translated to Swahili with the help of a native speaker).

"*Thank you all for coming to learn with technology today. Everyone did a fantastic job yesterday, and we are sure you will do the same today. We will leave you all to work by yourselves in the next hour. Please talk and help each other as much as you like. Everyone is a teacher and helper in this group. It is your job to provide your friends with help if they ask you for it. If your friend asks you for help, don't just show them the answers. Please teach them just like a teacher so they too can learn it like you. You can go to the bathroom or leave whenever you want. See you all later."*

For students in the experimental group, they were also be told the following.

"*When you are working with the system and you see this helper hand flashing, click it with one finger and it will show you a picture of one of your friends who can help you learn better. Please take you tablet and go to the student for help. Also, if you need to ask anyone for help, click on this helper button, and it will show you a picture of the friend to ask."*

7.3.2 Qualitative Video Observations from Experimental Sessions

No researcher or adult was present in the room with the students during the study sessions. Instead, these unsupervised sessions were video recorded from multiple angles to capture natural student interactions – all sessions lasted for one hour, and we collected data from 137 (68 control and 69 intervention) total sessions across all grades. I reviewed videos from all group sessions and recorded qualitative observations of the student interactions with the tablet and one another. In the control group (as well as baseline and final) condition, I annotated all non-adjacent student interactions with the time of the interaction, the helping and receiving student, as well as the type of help the student was providing e.g. application support, digital literacy or technical support, domain knowledge support, or information sharing. Every week, these annotations were reviewed with supervising members of the team who provided guidance of areas that needed further investigation. In the experimental conditions, the qualitative annotations were triangulated with the logs gathered by the system intervention on when each intervention was triggered, and the helper suggested. I annotated each of these system logs with the responses of the students who needed help, and the helpers suggested. For the qualitative observations, three members of the team reviewed the videos, notes, and observation logs to identify emergent themes related to help-seeking and help-giving behaviors, as well as student interactions with the system following a grounded theory approach [43]. We triangulated all observations related to these themes with logs captured by researchers in the field, debrief recordings, follow-up interviews with teachers, and photographs captured on site to ensure that all evidence were mutually supportive. After all sessions were categorized, all three members of the team reviewed the findings for all experimental sessions, discussed all areas of disagreement, and re-categorized findings as agreed upon by the entire team. Where necessary, we consulted with native Swahili speakers to help translate interactions, as well as provide insights on the cultural underpinnings of those interactions. This study design and data analysis methodology has been used and validated in previous learning science research studies e.g. [146].

7.3.3 System and Interaction Logs

We analyzed student performance, system activity logs, and insights from the video observations, focusing on their interactions with the helper system and with one another. We began our data analysis by running basic descriptive statistics gain high level insights on student performance, system interactions, and help-system insights. These high-level statistics provided insights and direction to properly annotate, analyze and triangulate our finding. Data gathered from this experimental study will be used to improve the error recognition and help timing models as well.

We reviewed the video and system logs to annotate when the system recommended a helper to a student, the type of error detected automatically, if the students actually looked like they need help, the type of help it looked like they needed, whether the student activated the helper button, and whether they followed through with the help suggestion. We also recorded other instances where it seemed like the students needed help but the system did not intervene.

Finally, we performed hierarchical linear regressions and independent t-tests to measure the effects of the helper system on student performance between the experimental and control groups.

System logs gathered from these experimental sessions were used to investigate the following hypotheses:

- H1 – Student Interactions:

a) Students in the experimental group will have significantly increased interactions with non-adjacent peers compared to the control group

- H2 – Activity Engagement:
  a) Students in the experimental group will have higher activity completion rates (adjusting for activity types) compared to the control group
  b) Students in the experimental group will have significantly increased selections of activities that are *perceived to be more difficult* compared to the control group.
- H3 – Learning Gains:
  a) Students in the experimental group will have a significantly higher math and literacy scores within the learning system compared to the control group
  b) Students in the experimental group will demonstrate higher pre- vs post-test gains compared to the control group

For these hypotheses, hierarchical and ordinary least squares linear regression models were conducted to understand the differences between the experimental and controlled conditions. Hierarchical linear modeling (HLM) or multi-level analysis is an ordinary least square (OLS) regression-based analysis that accounts for groups of units clustered together in an organized fashion such as students within classroom, age group, technology experience etc. It violates the independence assumption of OLS regression, because observation groups are not independent of one another. This analysis makes the following assumptions: data must be linear and normal, the assumption of independence is not required, and the regressors are expected to be correlated with grouping variables.

Video annotations from the experimental sessions were used to supplement data from the system logs. By adopting a partial-interval recording method [74], we broke each video session into 30 second intervals and for each child we will annotated the videos to indicate when students interacted with non-adjacent peer, the type of support that was provided to them, and qualitative descriptions of their interaction.

Below are potential regression models for the original hypotheses – these are all subject to change as data analysis. Each model was clustered by the group (as it accounts for the classroom and age differences as well), and the students will be added as a random effect as well. The cohesion coefficient was not included in the base model as groups are already balanced by their cohesion scores.

Baseline model for H1a:

$$\boldsymbol{H1a} < -\, lmer(NonAdjacentInteractions \sim factor(treatment_{condition}) + (1|group_{id}), data = dataset)$$

In the secondary model for H1a, I included interactions between the treatment and student ages, and the treatment and session numbers to determine if the treatment works differently for children at different ages, and with repeated exposure.

$$\boldsymbol{H1a} < -\, lmer(NonAdjacentInteractions \sim factor(treatment_{condition}) * age + factor(treatment_{condition}) * session_{number} + (1|group_{id}), data = dataset)$$

Baseline model for H2a:

$$\boldsymbol{H2a} < -\, lmer(activity_{completion_{rates}} \sim factor(treatment_{condition}) + (1|group_{id}), data = dataset)$$

Secondary model:

$$H2a < - lmer(activity_{completion_{rates}} \sim factor(treatment_{condition}) * age + factor(treatment_{condition}) * session_{number} + (1|group_{id}), data = dataset)$$

$\boldsymbol{H2b}$, $\boldsymbol{H3a}$ and $\boldsymbol{H3b}$ will be investigated using independent two tailed t-tests, and ordinary least squares linear regression models comparing the treatment to controlled groups.

7.4 Findings

For the sake of language consistency, the following grades are denoted by their short forms: Nursery 1 (N1), Nursery 2 (N2), Primary/Class 1 (C1), Primary/Class 2 (C2), and Primary/Class 3 (C3). Students who provide help will be referred to as “helpers”, while those who receive help will be called “beneficiaries”. Finally, ‘treatment” group or condition (vs control) will be used to refer to students who received our help-seeking intervention.

To begin our experiment sessions, we conducted baseline technology learning sessions with all 18 groups of students. Generally, the older students were, the lower the number of non-adjacent interactions they had with one another (Figure 36). This trend was not dependent on prior exposure to technology – students in both N1 and C3 had no prior exposure to our learning software before the baseline session yet interacted very differently with one another and the technology.

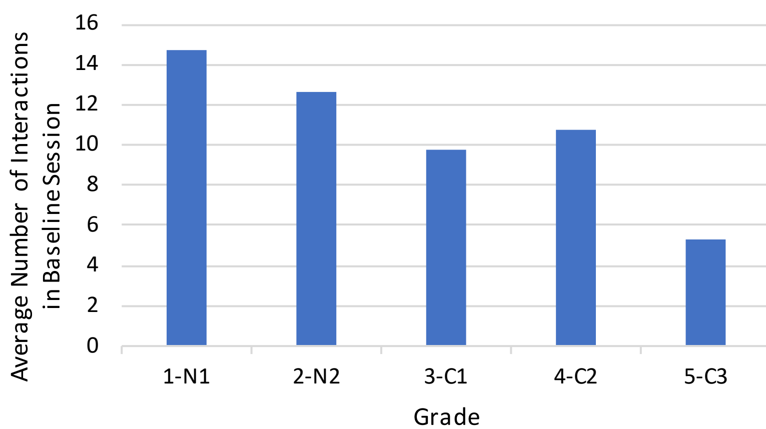

Figure 35: Number of Baseline Non-Adjacent Interactions by Class

Once the help-seeking intervention was introduced after the baseline (treatment session 1), students had varying reactions to it. The youngest students (N1) noticed the alerts going off but never actually activated it until the fourth session, when one student activated it and showed it to their friend. Although these young students were very excited to see their faces on the tablets, they never called their friends for help throughout the entire experiment despite being instructed to do so every session. Previous studies show that students are able to plan and collaborate starting from age five [209] – given that the youngest students in N1 were 5 years old, and it was the beginning of the school year, they may have been too young for in intervention.

Students in the other grades noticed and activated the intervention almost immediately and were also very excited to see their faces on the tablet. However, some never actually called their friends for help despite the system suggestions, while others called their friends who walked over and dismissed the intervention prompt, without helping, especially during the first two experimental sessions. There are several possible explanations for this behavior. First, while we instructed students to call on their friends for help, it was possible that helpers did not understand what that meant in practice which caused them to dismiss the intervention without actually helping. Also, our system highly depended on students listening to audio prompts to get placed in cognitively appropriate content, as well as follow the intervention instructions. Data from the recorded videos shows students bringing tablets up to their ears to hear instructions due to background noise from the other tablets and surrounding classrooms. As a result, most students got placed in content areas that were too easy and appropriate for Nursery school students, therefore did not need any help with the learning materials. To adjust for these difficulties, we instructed students to sit and work together on activities when called upon after session 3, and had a few students act out appropriate ways to help at the beginning of every session. We also adjusted our system to place all students in grade appropriate content areas starting from session 3 to reduce the dependence on sound for the knowledge placement tests.

7.4.1 H-1: Interaction with Non-Adjacent Peers

The Intervention elicits much higher movement from non-adjacent students

There were several incidents during the treatment sessions where the help-seeking intervention was triggered but students did not notice it, ignored it, or activated it but did not call their friends for help. However, students called on their friends much more overall in the treatment condition especially in the earlier sessions resulting in a higher number of non-adjacent student interactions. Figure 37 shows the average number of non-adjacent interactions in the control group sessions compared to the treatment groups.

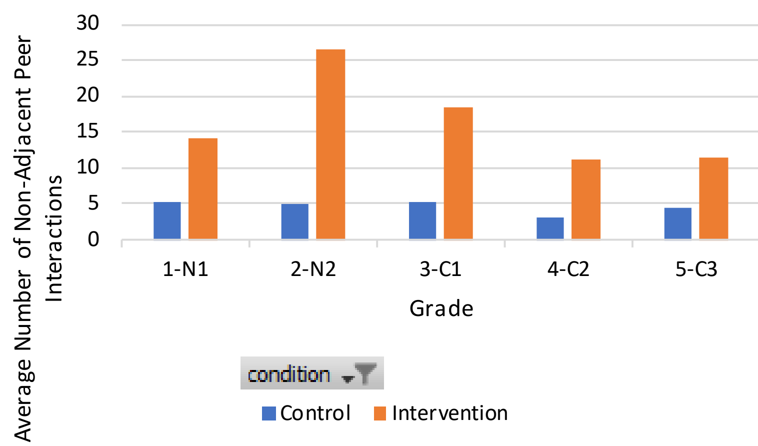

Figure 36: Average Number of Non-Adjacent Student Interactions in the Control vs Intervention Sessions

Like the control groups, students in the treatment groups called on each other for different reasons even without prompting by the intervention – the intervention did not alter normal student-student interactions. However, the intervention caused students to request for additional help, over what they would have requested unprompted.

The most prevalent type of student interactions without the intervention was for Information Sharing

Figure 38 shows the types of interactions that students requested help for comparing the control to the treatment condition.

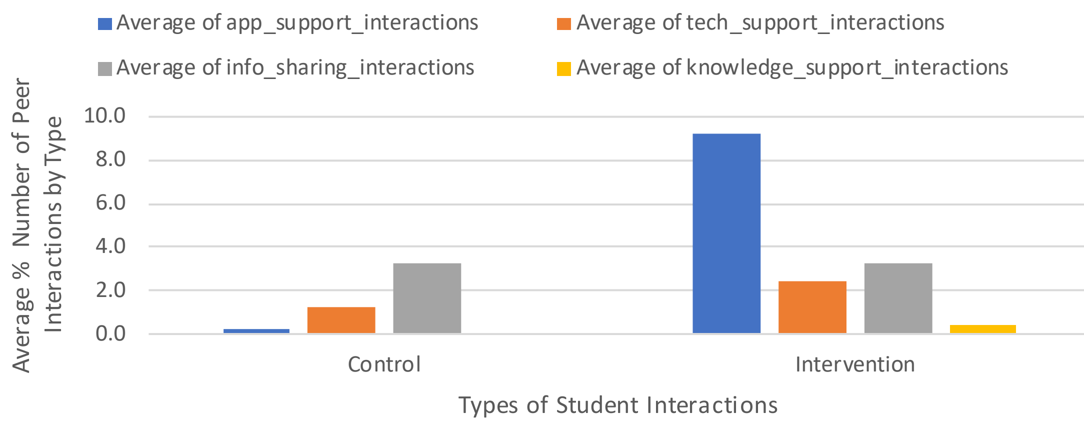

Figure 37: Types of Student Interactions in Control vs Treatment Condition

The most prevalent type of interaction observed in the control condition was information sharing – this was when students called on their friends to share a new activity or read a new story together. In the earlier sessions, students called on their friends more for technical support which mostly happened when their tablets were switched off and they needed help getting back in. Approximately 97% of the support calls triggered by the intervention was for application support (49.5% for application and gesture support, 47.5% was for hesitation support), and 3% was for knowledge support. We did not observe any calls for knowledge support in the control groups. The requests for application support requests in the treatment condition was only observed in the N1 and C3 grades – this was unsurprising because unlike other grades, they had no prior experience with the technology. Incidents categorized as "application support" included calls due to gesture support, application specific support, and calls due to student hesitation on individual applications.

We ran a hierarchical linear regression to determine if students in the treatment condition had significantly more non-adjacent interactions compared to their peers in the control groups. In the primary model, the group ID was included as a random effect to account for peculiarities associated with individual groups. Our results (Table 9) show that the help-seeking intervention caused students in the experimental groups to interact almost three times more than their peers in the control groups.

	Estimate	***Std. Error***	***t value***
Control Condition (Intercept)	5.015	1.746	2.872
Treatment Condition	11.029	2.46	4.483

Table 9: Primary Model – Hierarchical Linear Model on the Effect of the Help-Seeking Intervention on the Number of Non-Adjacent Peer Interactions

Following this analysis, we ran a secondary hierarchical linear regression model, including the student grades (to account for effects of student ages), and the session number (to account for repeated exposure) to the model (Table 10). Similarly, students in the treatment groups interacted with each other almost three times more than the control groups. Overall, the older students were or the more experience they had, they called for help less as a result of the intervention. These ***results confirm our hypothesis H1 – the intervention causes students to interact at a higher frequency with their peers.***

	Estimate	Std. Error	t value
Control Group (Intercept)	4.46	4.76	0.94
Intervention	11.13	2.35	4.73
Class - N2	5.38	4.32	1.25
Class - C1	0.94	4.36	0.22
Class - C2	-2.56	4.21	-0.61
Class - C3	-3.12	4.39	-0.71
Session Number - 1	11.00	4.58	2.40
Session Number - 2	0.06	4.58	0.01
Session Number - 3	-4.67	4.58	-1.02
Session Number - 4	4.06	4.58	0.89
Session Number - 5	-0.86	4.73	-0.18
Session Number - 6	-3.07	4.65	-0.66

Table 10: Secondary Model – Hierarchical Linear Model on the Effect of the Help-Seeking Intervention on the Number of Non-Adjacent Peer Interactions

Prior friendships do not affect students help-seeking requests from the intervention

Throughout our analysis of the data, we qualitatively annotated if behaved differently if the intervention recommended that they call on their friends for help. We found that students followed the system help recommendations regardless of whether their friends were suggested. Without prompting by the system, students tended to call on one or two students in the group who they perceived as knowledgeable to help them with application support or technical support issues. Students called on these popular helpers repeatedly regardless of whether they were in their friend network. In one session in C2, we observed a girl who wanted a specific student to help her with the problem she experienced on the tablet. The system repeatedly suggested helpers, and she activated it and dismissed the suggestions even when her friends were suggested. She continued this behavior until a specific boy was suggested and then she called him over for help.

It is important to note that although students never indicated that they were friends with their opposite-gender classroom peers, we found that girls interacted very freely with boys and vice versa in our classroom observations. These results might have been different if students were paired with peers who they have limited prior interactions with e.g. students from other classrooms, across other age groups, or other schools.

On the other hand, students were visibly more endearing to peers in their friendship network. When students originally discovered the help-seeking intervention, students often called on their friends to share their new discovery. Sometimes, students exchanged seats to be closer to their friends, and alerted their friends to activate the intervention when it was triggered. Friends also directed each other to pick specific content areas so they could work on similar activities. Figure 39 shows friends working together with (left) and without (right) prompting from the help-seeking intervention.

Figure 38: (L-R) Friends engaging with one another with and without prompting from the help-seeking intervention.

The intervention fosters knowledge support interactions, and students get better at monitoring their cognition over time

The previous subsections were focused on the *quantity* of student interactions as a result of the intervention – this subsection focuses primarily on the *quality* of the help requests. In all 69 treatment sessions observed, there was a total of twenty-nine calls for knowledge support. Table 11 shows the total number of help requests by support type in both the control and treatment conditions.

	Application Support	***Technical Support***	***Information Sharing***	***Knowledge Support***	***Average calls for request per session***
Control	13	82	224	0	***4.7***
Treatment	634	165	223	29	***15.5***

Table 11: Total Number of Help Requests by Support Type in Control and Treatment Conditions

Our learning system automatically adjusts content presented based on student performance, so we were not surprised by the few number of requests for knowledge support. However, in sessions where knowledge support interactions were observed, students demonstrated both knowledge telling and knowledge building interactions as a result of the help-seeking intervention.

On the appropriateness of the help-seeking intervention design, students recognized the helper icon and understood that its purpose was to allow them digitally raise their hands – like they did in their classrooms (Figure 40). We observed several incidents of students struggling with an activity, and repeatedly tapping the intervention for help. We also observed students redirecting their adjacent peers to tap on the helper icon if the peer were struggling with an activity that they could not help with. Like our previous experiments, we found that students who were called upon were quite persistent in their help-giving, working together until the student could navigate the activity unassisted. Students also sometimes used the help requests as opportunities to practice activities that they had not encountered on their tablets – persisting even after the help request was fulfilled.

Figure 39: Students recognize the helper icon as a way to digitally raise their hands

In line with our previous findings and related literature, most of the requests for knowledge support was provided using knowledge telling activities – helpers mostly answered questions for their peers without any explanations. However, we observed a few knowledge building interactions as a result of the intervention. In one session in C2 – a boy was struggling to complete an activity that required him to spell a word using its syllables. As a result, the intervention alerted him to call a girl for help and he did. She came over and answered the question for him, then went back to her seat. However, he continued to struggle with that activity and shortly after, the intervention alerted him again to call on another girl for help. This time, she pointed to his screen and said syllable out loud for him to hear before she tapped it and completed the word. She continued this behavior, saying each syllable out loud before tapping it on his tablet for several questions, and then returned back to her own work.

Students also got much better at providing quality help and monitoring their cognition over time. In the first few sessions, helpers dismissed most requests from their peers. Although the number of requests reduced with more experience with the intervention (Table 9 and 10), students started to call for help when they felt they actually needed some assistance, and not just because the system instructed them to. Figure 41 shows the percentage of help requests that helpers either dismissed or provided help broken down by classes over the six sessions.

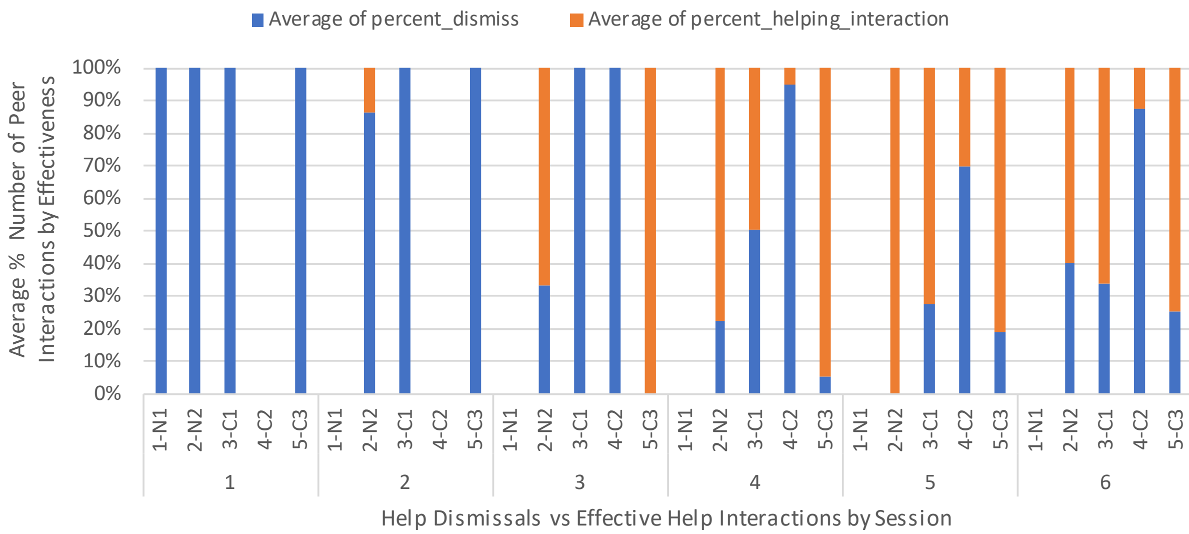

Figure 40: Percentage of help requests that helpers either dismissed or provided help for – broken down by grade over six experimental sessions.

In session 1 and most of session 2, helpers dismissed all help requests but started providing better help starting in session 3. Even though we became more explicit about demonstrating effective help interactions, students who needed help got much better at insisting that their peers actually help them when called. In all treatment groups (except for those in N1), we observed several incidents where students called helpers back who had originally dismissed their requests, students complained when their request were repeatedly dismissed, and even started ignoring suggestions from the help-seeking system if suggested a helper who typically did not assist when called upon. We also observed incidents where other students stepped in to help their peers if an assigned helper ignored or dismissed the help request.

Finally, we found that students in groups with higher overall pretest scores were more likely to provide help for their friends rather than dismiss help requests. We ran a linear regression to determine if the average group pretest score had an impact on the percentage of positive help interactions within sessions (Table 12). The results show that for every additional point in the groups average pretest score, there is an 8% significant increase in the number of positive help interactions when students are called upon in the group. The effects of the group pretest scores are magnified exponentially as students have more experience with the help-seeking intervention (as shown in the estimates from sessions 4-6). These results validate our insights from chapter 6 that higher achieving students are used to hearing about their brilliance from their teachers and more likely have experience with leading and helping their peers compared to their lower achieving peers; therefore they are more likely to provide help rather than dismiss help requests when called upon.

	Estimate	*Std. Error*	*t value*	*Pr(>|t|)*	*sig*
Average Positive Help Interactions (Intercept)	-2.50	2.11	-1.19	0.240603	
Group Pretest Score	0.08	0.04	2.15	0.035532	*
Session Number - 1	-0.05	1.90	-0.03	0.979191	
Session Number - 2	0.39	1.90	0.21	0.835829	
Session Number - 3	1.62	1.90	0.85	0.39738	
Session Number - 4	6.73	1.90	3.55	0.000785	***
Session Number - 5	5.19	1.96	2.65	0.010331	*
Session Number - 6	4.73	1.90	2.49	0.01558	*

Table 12: Linear Regression results analyzing the effects of group pretest scores on positive help interactions

Overall, results from this subsection show some promise that with proper training, careful group composition, and technology scaffolding, the young students can support their peers in ways bring about longer term learning of the material for both the helper and the requesting student.

7.4.2 H-2: System Engagement

(H2-a) Intervention makes no difference in student activity completion rates

To measure student engagement, we analyzed the system logs to determine if students in the treatment condition completed activities at rates different from the control groups. Figure 42 shows the average completion rates for math and literacy activities comparing the control to the treatment groups. Visually, the results seem dependent on the grade with the N2 and P2 treatment groups being slightly more engaged, while the others seem slightly less engaged.

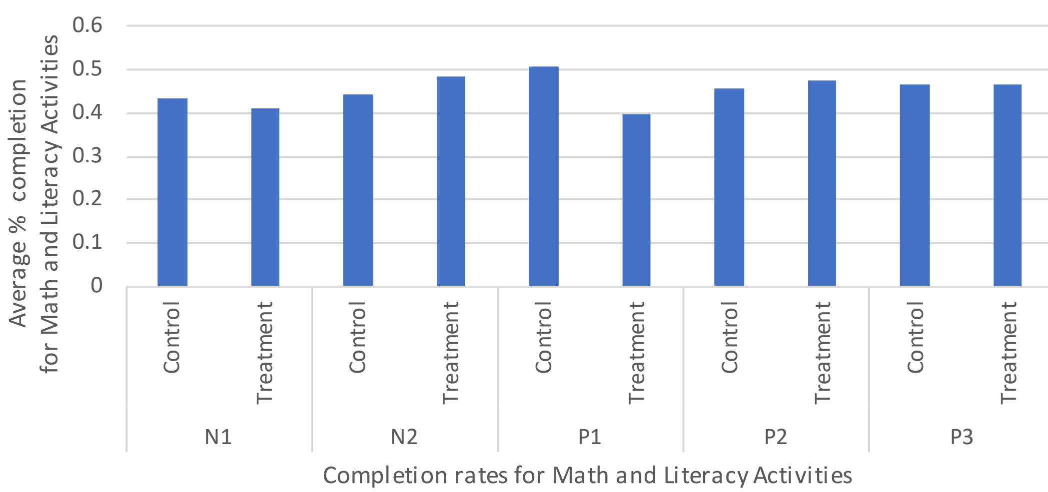

Figure 41: Average completion rates for math and literacy activities

To understand the statistical significance of these differences, we ran a linear regression model to determine if the treatment condition and the class significantly impact student activity completion rates (Table 13). The results show that overall, there was no significant difference in the activity completion rates between the treatment and the control groups. We found similar results even after running further analyses removing the interactions from sessions 1 and 2, as well as limiting the analyses to the math and literacy data subsets.

	Estimate	***Std. Error***	***t value***	***Pr(>|t|)***	***Sig***
Average Completion Rates N1 + Control Condition (Intercept)	0.43	0.02	17.59	<2e-16	***
Treatment Condition	-0.01	0.02	-0.54	0.587	
Class - N2	0.04	0.03	1.43	0.153	
Class - P1	0.03	0.03	0.94	0.347	
Class - P2	0.04	0.03	1.49	0.136	
Class - P3	0.05	0.03	1.49	0.137	

Table 13: Linear regression model comparing activity completion rates from control vs treatment groups

Although it is unclear why the intervention had no effect on activity completion rates despite the availability of additional help to complete activities, one possible explanation based on insights from of our previous study [198] is that for our participants and similar demographics, activity completion may be determined by how much students enjoy activities rather than their ability or the support they have for completing them. Therefore, our ***hypothesis H2-a is false – students in the treatment group do not complete activities at higher rates***.

(H2-b) Intervention causes students to select more difficult activities

Our learning system was divided into three main content areas – Math, Literacy, and Stories. The 'Math' and 'Literacy' content areas contained graded activities, while the 'Stories' content area mostly required students to passively listen to grade appropriate and culturally relevant stories. The easiest activities in our system were contained in the "Stories" area – students mostly listened to the stories and invited their friends to share interesting bits. Therefore, students content area selection was not only reflective of the material they wanted to engage in, but also how much effort they were willing to put into their learning at different points in the sessions.

In our learning system, there was a literacy learning application (SPELL) that prompted C2 students to call for help too frequently. This application was experienced by students in C1, C2, and C3, but most frequently by C2. The system prompted students to call for help before most of them got the chance to answer the questions on their own. We had very limited usage data on this application from our prior studies, therefore the timings were insufficient to prompt students appropriately. We observed students quickly get fatigued from moving about too often while learning with this application. Out of frustration, most students switched to the 'Stories' content area (and prompted their friends to switch as well) for the rest of the session. Although, the application was not in the 'Math' content area, they avoided all the graded activities until the beginning of the next session. This observation provided evidence that students migrated to 'Stories' as a way of avoiding harder activities.

Figure 43 shows that for every grade (including N1 students who did not follow any of the intervention suggestions), the treatment group selected the ‘Math’ and ‘Literacy’ content areas at a higher frequency than the students in the control groups. Table 14 shows the results of a linear regression to determine the statistical difference in students content selection choices – the results shows that students in the treatment group selected harder activities an average of 4% more than the control group. These results are statistically significant even after we controlled for individual groups.

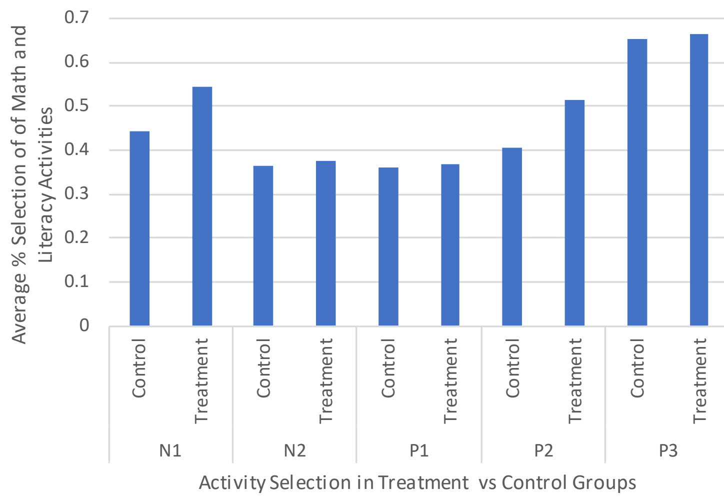

Figure 42: Activity Selection in Treatment vs Control groups.

	Estimate	*Std. Error*	*t value*	*Pr(>|t|)*	*Sig*
Control Condition (Intercept)	0.44217	0.01448	30.544	<2e-16	***
Treatment Condition	0.04893	0.02018	2.424	0.0156	*

Table 14: Linear Regression Model for Student Math/Literacy vs Stories Content Selection

We were surprised by these results especially for N1 as they did not use the intervention in the way that we originally planned. However, all students were excited to see their faces on the tablets regardless of their use of the intervention. For the Nursery students, the possibility of seeing their faces on the tablet likely caused them to select the math/literacy activities more, and as a result, engaged in more cognitively challenging activities. Even the Nursery students who do not use the intervention, likely go there to see their faces and as a result engage in more cognitively challenging activities. For the other students, the guarantee that someone will be available to assist them if they ran into any trouble likely caused this behavior. These results show that our ***hypothesis H2-b is true – the intervention causes students to select harder activities within the learning system.***

7.4.3 H-3: Learning Gains

To assess students learning, we analyzed students’ performance within the learning system, and on a paper-based test.

(H3-a) Students score similarly within the learning system
On the learning system, we expected that students in the treatment condition will outperform their peers in the control groups because they had assistance with any application and knowledge related issues they encountered. Figure 44 shows the average score differences in math and literacy comparing the treatment to the control groups. Contrary to our expectations, the treatment groups only outperformed the control groups in the grades that used the intervention the least (N1 and N2), while students who used the intervention most effectively scored slightly less than their control group peers.

We ran a linear regression model (Table 15) to understand the significance of these differences – the results show that both the control and treatment conditions score the same on average and the differences are not statistically significant. Given that the number of help requests related to knowledge support were so few compared to the other support types during the experiment, it is no surprise that overall, students in the control group did not perform better than those in the treatment groups. However, the linear regression results reveal peculiarities for specific groups that required further investigation using the video data captured from the experiment sessions.

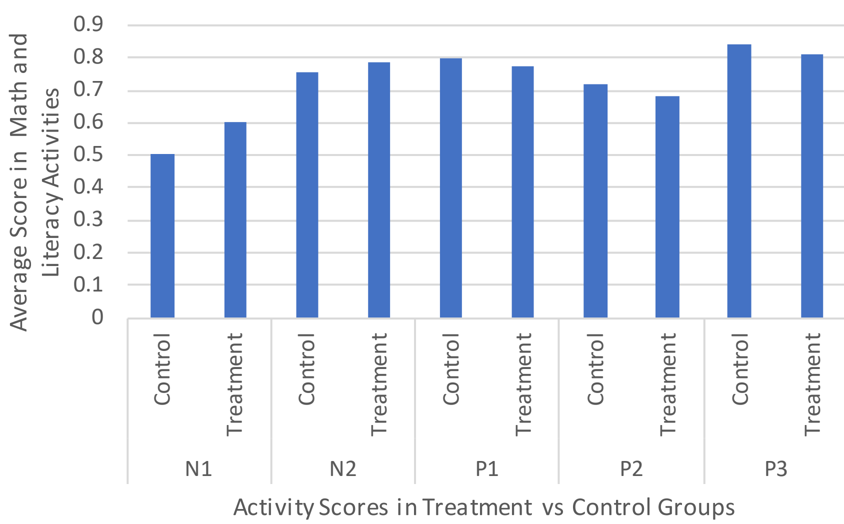

Figure 43: Average scores in Math and Literacy Activities

As shown in Figure 44, students in N1 perform significantly worse than the control group in C1 – with the control group performing even worse than the treatment group. These students were the youngest, had no prior experience with the technology, and did not utilize the help-seeking intervention so their results were unsurprising. The other group of interest was the Treatment 1 group in C2. The issue described in the previous section with the SPELL application disproportionately affected the treatment groups in C2. Therefore, we reviewed the video footage in the two treatment groups in C2 understand why the scores were so different in the Treatment 1 vs Treatment 2 groups since they faced the same issue. The issue with the SPELL application began in session 4 for both groups.

We found that students in the C2 - Treatment 2 group quickly recognized that the application prompted them too frequently to call their friends for help and they all spent the first 30 minutes moving non-stop. After 30 minutes, one student abandoned the literacy content area and prompted the other students to follow suit. From that incident until the end of the experiment, students in Treatment 2 immediately abandoned the SPELL application whenever they encountered it, and hardly used the intervention anymore until the end of the study. However, students in Treatment 1 persisted much longer with this application, and even after they abandoned it in session 4, continued trying to engage with it until the end of the experiment costing them very valuable learning time. These results show that without reliable timing data on the individual activities, the effects on student performance can be devastating. Our analysis shows that the hypothesis ***H3-a is not confirmed, students in the treatment condition did not perform better than those in the control condition on activities within the learning system*** as they faced additional difficulties with a defective learning application. To evaluate the hypothesis as true or false, we need to solve all application timing related issues and gather the data over a longer period to determine the intervention's effect on student learning within the system.

	Estimate	Std. Error	t value	Pr(>|t|)	Sig
Class 1 + Control_1 Condition (Intercept)	0.80	0.06	14.00	< 2e-16	***
Treatment Condition	0.01	0.07	0.12	0.90	
Nursery_1_Control	-0.29	0.07	-4.15	0.00	***
Nursery_1_Treatment_1	-0.20	0.06	-3.30	0.00	**
Nursery_2_Control_1	-0.10	0.07	-1.41	0.16	
Nursery_2_Control_2	0.04	0.08	0.52	0.61	
Nursery_2_Treatment_1	-0.04	0.07	-0.55	0.59	
Class_1_Control_2	0.00	0.08	0.04	0.97	
Class_1_Treatment_1	-0.04	0.07	-0.52	0.61	
Class_1_Treatment_2	-0.02	0.07	-0.24	0.81	
Class_2_Control_1	-0.06	0.08	-0.82	0.41	
Class_2_Control_2	-0.09	0.07	-1.27	0.21	
Class_2_Treatment_1	-0.23	0.07	-3.37	0.00	***
Class_2_Treatment_2	-0.01	0.07	-0.20	0.85	
Class_3_Control_1	0.05	0.07	0.66	0.51	
Class_3_Control_2	0.05	0.08	0.58	0.56	
Class_3_Treatment_1	-0.02	0.07	-0.30	0.76	
Class_3_Treatment_2	0.04	0.07	0.51	0.61	

Table 15: Linear Regression Model - Average scores in Math and Literacy Activities

(H3-b) No short-term additional increases in learning gains on the paper test

Given that students only used the help-seeking system properly for 3 to 4 sessions, the results from H3-a, and the few number of requests for knowledge support, we did not expect to see any learning gain differences as a result of the intervention (although our hypothesis states otherwise). With the issues encountered with the SPELL application, we were interested to see if those struggles affected the learning gains on a paper-based post-test of the students exposed to them (C1, C2, and C3).

Table 16 shows the average pretest score per group, along with the learning gains (post – pretest score) in both math and literacy. The results suggest that groups with higher pretest scores gain less overall on the paper tests. This was not surprising as some students already scored close to the maximum score before they began the experiment, therefore had less room to improve on an equivalent post-test compared to students with lower pre-test scores. We then ran a linear regression to determine the correlation between student pretest scores and the treatment condition on student overall learning gains. The results are presented in Table 17.

	Group	Average Pretest Total Score (max 59)	Math Learning Gains	Lit Learning Gains
Nursery 1	N1_Control_1	8.29	6.00	3.47
	N1_Treatment_1	14.12	2.39	2.71
Nursery 2	N2_Control_1	34.40	1.37	3.26
	N2_Control_2	39.11	0.43	0.94
	N2_Treatment_1	39.43	0.73	0.46
	N2_Treatment_2	30.25	4.28	3.00
Class 1	C1_Control_1	46.40	-0.20	0.00
	C1_Control_2	45.71	0.50	0.21
	C1_Treatment_1	47.45	0.13	1.26
	C1_Treatment_2	52.95	-1.37	0.00
Class 2	C2_Control_1	51.00	2.00	0.33
	C2_Control_2	48.63	3.32	0.42
	C2_Treatment_1	45.87	0.97	0.89
	C2_Treatment_2	49.37	3.30	0.00
Class 3	C3_Control_1	51.94	2.45	0.81
	C3_Control_2	54.00	2.67	0.33
	C3_Treatment_1	57.48	0.52	0.00
	C3_Treatment_2	55.65	-0.25	0.35

Table 16: Average Pretest score, math and literacy learning gains for the control and treatment groups.

The regression results show that students in the treatment condition gain 0.78 points less on the average on the post test, however, the strongest determinant of students learning gains is their pretest score. For every additional point on the pretest score (max score 59), students gain 0.15 less overall. As stated earlier, the effect of the pre-test on students learning gains was because they just had less room to grow – similar results have been found in previous studies [85].

	Estimate	*Std. Error*	*t value*	*Pr(>|t|)*	*Sig*
Control Condition (Intercept)	9.84	0.44	22.45	<0.01	***
Treatment Condition	-0.78	0.30	-2.61	<0.01	**
Pretest_score	-0.15	0.01	-16.41	<0.01	***

Table 17: Linear Regression Model - correlation between student pretest scores, and the individual groups on student overall learning gains

We also found it surprising that students in our treatment condition gained significantly less than the control condition – we expected similar results and even hoped for slightly better gains. There are several possible explanations to this trend – students in the control groups just spend more time focusing on their individual work compared to the treatment group who have to split their attention between multiple students (student movement). Another explanation is that the intervention itself is distracting to students and breaks their concentration in ways that affects their learning. Finally, issues related to intervention trigger timings on the individual applications e.g. SPELL may have affected student learning gains overall.

We do not have data from this study to measure whether the intervention itself was distracting to students e.g. eye and face tracking data or quantitative measures of students' emotional responses to the intervention. However, we have data to investigate the effects of students leaving their work to help others, and the time they spent on the SPELL application on their learning gains. It is important to note that although students in the control and treatment conditions experienced this application, only students in the treatment condition experienced the effects of the frequent interruptions for unnecessary help. Therefore, we ran a secondary model to include the number of times students left their seat to help a peer, and the amount of time (in minutes) that students spent in the SPELL application - the results are shown in Table 18.

	Estimate	*Std. Error*	*t value*	*Pr(>|t|)*	*Sig*
Control Condition (Intercept)	13.11	1.79	7.339	<0.01	***
Treatment Condition	-0.27	0.57	-0.478	0.63	
Pretest Score	-0.22	0.04	-6.271	<0.01	***
SPELL Time (Minutes)	0.01	0.06	0.01	0.93	
Student Movement	-0.11	0.06	-1.908	0.059	.

Table 18: Secondary Linear regression model accounting for the effects of student movement and the time in the SPELL application on learning gains

Including the time students spent in the SPELL application, and the number of times students moved from their seats in the secondary model explains why students in the treatment condition scored lower than the control group in the original regression model. The results also show that for every time a student moves from their seat, their average learning gains reduce by 0.11 (slightly significant).

Our hypothesis ***H3-b is not confirmed – students in the treatment group gained less from the learning system compared to the control groups***. This was because they spent more time moving around unnecessarily due to a defective learning application rather than focusing on their work. We need to gather additional data over a much longer period updating all application timings, possibly making the design less distracting, and only alerting students when they cannot recover on their own. These changes are the minimum required to determine how such a system can possibly benefit students learning especially because it elicited very promising knowledge support interactions. We also need to investigate how to redesign our learning activities, applications, and even our paper tests so both higher and lower pretest students can benefit equally from our system, and we can measure those gains accurately.

7.5 Discussion

Interventions such as the one deployed in this study fall broadly under the category of Adaptive Collaborative Learning Support (ACLS) systems. ACLS interventions generally focus on improving collaboration between students, group formation, and supporting domain knowledge – they provide benefits to student learning over individual work or collaboration with no or non-adaptive support [12,100,168,208]. *However, our system is designed specifically to cater to the needs of K-2 students in low-resource and rural communities and is applicable regardless of students' language and culture as it does not rely on language comprehension to provide interventions*. Some ACLS systems rely on analyzing students' spoken or chat dialog (e.g. [205,208]) and use that to provide recommendations for improved tutoring interactions. Others rely on metrics such as periods of silence during conversations and/or utilizes machine learning classifiers to infer the quality of student interactions [100,166,167,205,206,208]. In addition, some others rely on students to classify their own utterances on the system (e.g. [13,115]) however, those have only been validated to be effective with high school and college students. While such systems are effective in areas where a single (or known) language is spoken, students in rural areas in Africa routinely speak multiple languages and may not be fluent in the official language of instruction [226] – rendering interventions dependent on preset languages potentially ineffective. In our search for research conducted with ACLS system, we did not find any that were specifically designed for students with low digital literacy, who may need assistance with navigating a technological device or learning about the mechanics of different learning applications. Our system supports struggles that students with low digital literacy are more likely to experience including support for touchscreen gestures, and helping students overcome application errors unrelated to domain content.

Our system was also designed to foster equitable help-seeking in group learning settings rather than pre-assigned tutor-tutee student pairs in traditional ACLS systems. Systems such as [192,208] pre-designate assigned student pairs or groups and the system intervenes to resolve conflict, improve collaboration and the quality of student interactions. Such systems do not consider the social dynamics that students may experience and may exacerbate existing norms of unequal distribution of help-giving responsibilities in the classroom. Insights from our classroom observations and teacher interviews show that lower achieving students rarely get opportunities to provide support for their peers in the classroom. In fact, teachers shared that low achieving students are afraid to speak up in group learning scenarios even when they know the correct answers. With such existing social dynamics, lower achieving students are likely to relegate themselves to the position of the tutee in assigned pair situations even when they are explicitly designated as tutors. We see evidence of this trend in the results from our experimental study in chapter 7 – groups with a higher number of lower achieving students have fewer positive helping behaviors. Given that our system caters to much more than domain knowledge issues, this allows for the opportunity to design help interactions in a group to be more distributed across students regardless of academic ability. A student might be the best in math in a group, but have little prior experience working with education technologies and can benefit from help from their lower achieving peers to learn effectively. Therefore, our system fosters help-giving interactions in a way that allow lower achieving students to demonstrate their mastery in other important areas directly or indirectly related to learning content. Potentially, the confidence that they build providing effective support to their higher achieving peers builds their confidence in other domain related content areas and promotes more equitable helping behaviors in the classroom.

Our research study provides valuable insights on the benefits of incorporating technology-mediated help-seeking scaffolding into the practice of young students learning with technology unassisted. It also provides critical insights on how detrimental such a system can be to students learning if not executed properly. To begin, our help-seeking intervention fostered knowledge support interactions that were not observed in any of the control groups. These interactions are the most critical of all the support types we tried to cater for, as it is traditionally the primary responsibility of teachers. In unassisted learning situations, students need additional support when they cannot attain new knowledge independently. Previous studies in this cultural context such as [199,200] have shown that without proper scaffolding, students have difficulty providing this support for one another, and an intervention such as ours can help students become better at it. We show evidence that students became aware that the help-seeking system was a tool that allowed them find support when they needed it – students repeatedly tapped (or their friends directed them to tap) on the intervention when they needed help even when the system did not detect any struggles. This type of capability not only gives students the agency to request support when they need it, but also allows students to choose whether they want to accept or reject the suggestions without publicly informing other members of the group.

Our intervention also propelled students to engage in more cognitively challenging activities. For the youngest students, this might have been due to the excitement of seeing their faces on the tablets. For their older counterparts, they may have had increased confidence and comfort knowing that they had support if they ran into trouble. This insight has implications for how educators and researchers organize learning content especially for activities that students do not traditionally enjoy. As our data shows, students are more likely to gravitate to activities they enjoy most, or those that are less cognitively tasking. This is not at all unique to students in Tanzania – several studies have shown similar results for students from other demographics [47,57,125]. Designing engaging and enjoyable activities should be a primary goal for educators, learning scientists, and technology designers, however, it is sometimes difficult to balance student engagement with maximizing learning goals. It is especially difficult to design activities that are engaging for demographics such as our study participants where there is limited existing research on. Researchers often use technology as a probe to investigate activities that students find the most engaging [125] but that can be unreliable when technology itself is foreign to the target demographic. As researchers spend more time investigating ways to design activities that maximize both student engagement and learning, interventions such as our help-seeking system can allow students to further engage with existing learning activities as more engaging ones are being developed.

An indirect but highly beneficial aspect of our help-seeking system is that it allowed for better self-monitoring of students' cognition. As students in our treatment condition spent more time with our help-seeking intervention they got much better at only calling for help when they actually needed it, regularly insisting that their peers help them if they were dismissed, and used the intervention to call on particular students depending on the type of help they needed. Students in the control groups (and in our previous two studies with this demographic) did not exhibit this level of agency and control on understanding when they needed help and who they needed it from. Although we did not find any studies directly from Tanzania (or even Africa), there is some research on interventions that specifically boost self-regulation and metacognitive skills in preschool to elementary school aged children e.g. [215]. Existing strategies that have shown positive results for improving students self-cognition include training kindergarten teachers about self-regulation e.g. in [150]. Meichenbaum et al. [117] found that primary school students with teachers who used strategies such as think-alouds, reciprocal teaching, and cooperative learning showed better monitoring of their own cognition while learning. While most research conducted on this topic focus on implementing strategies in a traditional classroom environment, our research shows that technology-based interventions that employ similar strategies (our system fosters reciprocal teaching and cooperative learning) can also produce similar benefits. Longer term studies of such interventions are required to determine if these skills lead to improved learning gains on traditional tests.

Our system intervention also granted students what we might term "social permission", that is, the feeling of freedom to request for help from specific students while learning with the technology while reducing the face threat of making such a request. Students could have very easily turned around and called on any of their peers for help, but they relied on the system for permission seek help in an environment where they were not mandated to accept the system recommendations unlike peer assignments from a teacher. Even more than giving students permission, our system provided them with knowledge of the specific peers that could help resolve their issues, providing them knowledge about students' ability that they would have not been aware of otherwise. Incorporating such technologies in the classroom can potentially make students aware of their own abilities (in addition to their friends) in ways that encourage them to answer more questions in the classroom.

Such awareness is not only relevant for students, but also teachers as well. Insights from chapter 6 showed that teachers formed impressions of students' abilities categorizing them as high, mid, and low achievers, and relied on high achievers only as the custodians of knowledge in group learning scenarios. Teachers in our study did not communicate any ways that they re-evaluated these formed impressions to move students to other categories when appropriate. Providing teachers with data on how students abilities evolve, as well as a wider range of the *types* of support that students can provide is likely to lead to a more equitable distribution of responsibilities in learning group, and reduce the anxieties that lower achieving students face that prevent them from speaking up in groups.

For personalized learning systems such as ours where content is adjusted to students' knowledge levels, it may seem redundant to design an intervention that fosters peer-peer knowledge support for students. However, our study shows that although these requests occur infrequently, they happen often enough that learning systems need to account and design for them. Students may also need additional support if a system focuses on testing and practice rather than actual teaching of educational concepts. In the short period of our research study, we did not see any differences in student learning based on the additional knowledge support however it is worth exploring over a longer period to determine how improvements to the system might affect student learning. There are also other metrics that can be assessed in future iterations of the intervention to explore other potential benefits of our system. For example, an increase in the percentage of positive help interactions for students in lower scoring groups might illustrate that the system is leading to increased confidence among lower achieving students on their abilities as helpers. Rather than just focusing on students' academic achievements, our future studies can employ interview and survey instruments validated in studies with young children to measure improvements to their metacognitive awareness (e.g. [183,222]), help-seeking and interpersonal cohesiveness (e.g. [30,187]), and their collaborative skills (e.g. [73]) as a result of the intervention. Additionally, technological improvements can be made to our system by utilizing the camera and microphone to determine how long students spend, and how much discourse they engage in as a measure of the quality of help students provide.

Despite the potential benefits of such a system, our research shows that if not executed correctly, such a system can be detrimental to students learning even in a short period of time. Students in our treatment condition gained an average of 92% of the gains made by our control group because they spent too much time in an application with inaccurate timing triggers, and the system prompted them to support their peers for issues that they could have overcome on their own. Students seemed to enjoy supporting one another in the treatment sessions, however, this should not have come at the expense of their learning gains. If these detrimental effects could have been observed even in the short term, they are potentially much more devastating if students are not able to work around system issues on their own. It is critical that before such a system is deployed, researchers take the time to gather representative application timings to prevent reduced learning gains as we saw in our research study. Although we conducted three rounds of pilot testing with our help-seeking intervention (two in the United States, and one round with our target demographic), such problems were only observable over a large volume of users tested over a considerable amount of time.

These insights cause us to ask this very important question: what kinds of help and support should technology be scaffolding, and which ones are unnecessary (or even detrimental) to students learning? Our help-seeking intervention designed for the following kinds of support: Application and gesture support, student hesitation, and knowledge support. Application and gesture support mostly benefited students without prior exposure to technology. However, data from the control group showed that students were able to overcome these difficulties with help from other students around them and did not need the additional triggers from the help-seeking intervention. Existing support features in our system such as demo videos of each application prior to first use and usage scaffolding within activities helped to alleviate many issues that required application support. To determine the additional benefit of this intervention (above that already incorporated into the system), it is important to resolve all application related errors resulting in the alerts getting triggered too frequently. It might be worth considering reducing the occurrences of these intervention types even more – allowing students more time for productive struggle to see if they can overcome these errors on their own to allow them spend more time with their tablets. Hesitation support was incorporated to bring students attention back to their own tablets; however, this came at the detriment of other students learning. Therefore, a more productive solution may involve triggering the intervention to regain students' attention, but not recommending any students for support – such a change will eliminate an additional 47.5% of student movement within the groups, causing students to move from their seats only when absolutely necessary. It is important to emphasize that some students in our target demographic demonstrated that they could engage in beneficial information sharing and technical support discourse amongst one another without the system intervention. These recommendations might not apply for students who need additional help fostering basic interactions.

Our system intervention shows some promise but requires improvements and further investigation to determine how beneficial it is for student learning. Our research study gave us an opportunity to gather almost 700 hours of student usage logs and application timings – this is sufficient for improving the timing models for all our applications to prevent the errors encountered in our study. Eliminating application and student hesitation support will reduce 97% of the calls to other students and allow students to help one another only during times when the system alone is not sufficient i.e. knowledge support calls. Students in both the treatment and control condition called on one another without prompting by the system intervention to share new information and activities with one another. These interactions are beneficial to student learning and group rapport and will remain unaffected even if we eliminate the calls for application and hesitation support. While the calls for knowledge support did not show any benefits for student learning for the duration of our experiment, the productive nature of those interactions make it worthy of further investigation on a much longer-term study.

Student should also be allowed to request for help from the system when they need it. We disabled this feature to prevent students from abusing the system, however, our data shows that students repeatedly tried to activate the intervention when they were genuinely struggling without success. Although students may abuse that feature due to excitement at first, this is likely to be normalized over time and used appropriately. The key factor to consider here is that students in our study demonstrated the need to maintain the agency of when they decided to call for support, and from whom. Our system helps to facilitate their requesting for peer support in areas where they may have trouble unassisted e.g. with knowledge support. Students shows that they valued the presence of the system when they needed support – rather than just calling out to their peers, they routinely tried to have the system suggest helpers before they could initiate those interactions.

Finally, our results suggest that there are some changes that can be made with the group composition that may improve the quality of help that students receive. Prior studies show that when students are left on their own, they tend to create more homogenous groups which may not always be the most beneficial for their learning [144,156]. The benefits of heterogenous groups are well established in the learning sciences including improved performance, creativity and innovation, and long term problem solving [19,145,162]. The quality of learning in heterogenous groups is enhanced by student diversity – heterogenous groups have been found to outperform homogenous groups on individual student learning gains [137]. Researchers need to critically examine the factors that lead to improved performance when learning with technology to help them create effective heterogenous groups; these factors will differ across populations. In our study, groups with higher average pre-test scores provided higher quality help compared to groups with lower average pretest scores. Students also interacted without hesitation across gender and did not show preference for their friends based on the systems suggestions for peer support. Therefore, rather than balancing groups by prior friendships, groups created based on random assignment while ensuring that students with high pre-test scores are distributed evenly across all experiment groups may maximize the efficacy of our help-seeking intervention.

Chapter 8 – The use of smart devices to improve formal education in rural Tanzania

As a research community, we have made significant strides in exploring the potential of technology to reduce the educational disparities in sub-Saharan Africa. There have been both small and large research initiatives in different African countries that have shown promising results for childrens' learning. One of the most prominent efforts was conducted by the Global Learning X-Prize initiative [65]. Over 2700 out of school students in rural Tanzania were supplied with learning tablets pre-loaded with educational software. After 15 months of students spending an average of 1 hour with the tablets, they gained the equivalent of 1 years' worth of formal education in reading, writing, and mathematics. Other prominent efforts are run by large companies e.g. One Billion learning company has offered tablet-based early literacy education to children in Malawi, Uganda, and Kenya since 2014 [227], Eneza Education offers SMS-based revision and learning materials to over 6 million learners in Ghana, Kenya, and Ivory Coast [228], and Bridge International Academies builds physical schools provides teachers with tablets preloaded with learning content and teaching scripts [229].

Smaller companies and education researchers have also joined the technology-based education race with tablet and multimedia applications (such as BRCK in East Africa [230] and Ubongo Kids in Tanzania [231]), desktop computers e.g. [2,111,122], and SMS-based interventions e.g. [95,112,153,154,232]. These efforts have shown some promise with regards to improving learning outcomes for students, but their success is too often limited with "unexpected" issues such as inadequate infrastructure, families not being able to afford the costs of these technologies, or their solutions not being feasible for several of their target populations. Many times, these realizations occur after very large financial investments in technology initiatives that are not sustainable for the target populations, limiting their success. Until researchers and education practitioners are able to prioritize local contexts and long term sustainability in the design of learning technologies, these financial resources may lead to better learning gains if spent on traditional education improvement initiatives with proven long-term benefits e.g. building more classrooms, hiring teachers, and supplementing the cost of school supplies and books [210].

In the next section, I discuss some specific problems related to how education technology research and deployments are currently conducted in Sub-Saharan Africa. This is in no way intended to denigrate education technologies as a potential solution for addressing educational disparities as a whole. Rather, its intention is to highlight research and industry practices that despite how well-intended they are, do not lead to long term improvement in the overall state of education in the region. My hope is that it helps researchers and education practitioners re-examine their efforts and re-allocate their resources in ways that leads to the deployment of EdTech that lead to sustainable learning gains and economic benefits for the residents of their target communities.

Problems with Education Technology Research and Deployment in Sub-Saharan Africa

Research conducted in the HCI/ICT4D communities about the educational disparities in Africa often present problems in monolithic terms – justifying the need for their interventions using statistics aggregated over the entire continent. These statistics often do not distinguish between important contexts such as urbans vs rural areas, countries and individual cultures, home vs school use etc. Also, the opinions of key stakeholders e.g. teachers and local custodians of knowledge are rarely presented, cultural ways of learning are not prioritized, and interventions are commonly experimental without long lasting benefits to the local communities. These broad generalizations make it difficult to understand root causes of these educational disparities, leading to the creation of a plethora of interventions that do not show long term improvements to these disparities. As such, this dissertation was conducted following a design case study framework [219] – first we conducted multiple studies to empirically analyze the learning practices of a specific usage context [198–200], then we created a technical artifact and investigated its feasibility and short-term efficacy for improving learning in this study. Finally, we recommend ways to improve the artifact for use over a much longer time period. Research studies conducted for this dissertation provides insights that respect traditional ways of teaching, amplify the voices of teachers and school administrators, and critically examine technological interventions both for its efficacy and its appropriateness for this demographic.

The scale of Africa's education disparities biases us to believe that we need solutions that match the problem's scale, disregarding the diversity of culture, resources, and infrastructure in different parts of the continent. As HCI practitioners, we advocate for the importance of context in the deployment of technological interventions, yet we too fall into the trap of a technology-first approach with regards to tackling these educational issues. Also, mobile devices are growing at an alarming rate in Africa leading to the large number of mobile-based educational solutions. However, these numbers are mostly reported from largely populated urban cities; we then take those insights and try to apply them to rural populations that neither have the same mobile infrastructure nor can afford smart devices. Finally, the vast majority of published research on the use of education technology in Africa are conducted by research teams who come from Europe and the United states [25,139] – without equal partnership collaborations from researchers who live locally and have a better understanding of the root causes of educational disparities. These problems are exacerbated by researchers not taking advantage of the interdisciplinary nature of HCI and collaborating with colleagues from traditional education and cultural studies research areas. Despite the best intentions of foreign researchers, they are likely unaware of effective teaching methods employed by the target demographic or issues that may prevent their interventions from being successful leading to solutions that "make logical sense" according to existing research, but fall short when applied in specific contexts.

As education research in Africa becomes more mainstream in the HCI and ICT4D communities, researchers need to start shifting from wide scale solutions, to prioritizing local contexts and stakeholders to design technology solutions that provide sustainable benefits for local communities. We must transition away from research studies that investigate whether Africans can learn with education technologies and instead, investigate how to create and deploy interventions that are sustainable and ultimately improve the education disparities on the continent. Much more than tailoring solutions for individual countries, we **at least** need to consider the following differentiating factors – deploying educational interventions in urban vs rural areas, and in traditional schooling environments vs unstructured settings. These contexts usually dictate how much money and time families can dedicate to learning technologies compared to their other responsibilities, the available infrastructure e.g. mobile data and electric power, and the feasibility of a given intervention as an appropriate solution given other competing environmental factors.

Affordability is a socio-economic issue that affects people regardless of whether they live in an urban or rural context, but rural areas are likely more affected by this. This issue is not unique to low income students from Africa – the COVID-19 pandemic shone a light on urban cities in the United States with large socio-economic inequalities (e.g. Pittsburgh, Pennsylvania) that were unable to transition to a technology-based education [233]. Poorer families had limited access to computers and internet at home, or did not have the time or the competence to assist their children while learning. Infrastructural challenges are mostly a problem for rural areas. Without power or internet, there are several education technology solutions that are impossible to deploy. Finally, the feasibility of technology intervention in different contexts matters as other environmental challenges such as security, lack of clean water, or knowledgeable adults may hinder the adoption of promising educational technologies. In the next few sessions, I will draw from existing research and insights from our research studies to recommend possible educational solutions that are worth investigating in unstructured and formal schools settings in both rural and urban areas in Tanzania. These recommendations are broad and admittedly make generalizations about culturally dissimilar communities that have economic similarities – there will always be communities that are exceptions e.g. urban areas with limited internet access, and rural areas with adequate power and mobile internet etc

Education Technology Interventions in Rural Areas

Rural areas are often the target of technology based educational interventions, despite the fact that 73% of Tanzanians live in urban areas [234]. Regardless, the need for education interventions in rural areas is valid because there is a much greater chance that schools are completely inaccessible to students. Like parents everywhere in the world, parents in rural areas want the best opportunities for their children. In chapter 4 of this dissertation, we show that parents are interested in the advancement of their children's education, often contributing to feeding students and working on school grounds for their children to remain enrolled. Other studies such as [104,112] show that neighbors and friends take over children's responsibilities to allow them learn both at home and at school. Despite this value that adults place on education, there are challenges in rural areas that limit the sorts of interventions that have long term feasibility and sustainability for improving education in rural areas.

The X-Prize global learning initiative was one of the largest scale attempts to deploy education technologies to over 2700 out of school children in rural Tanzanian villages – students gained 1 years' worth of math and reading proficiency over a 15 month period [65]. Yet, such a large-scale initiative required tremendous costs on items that were not directly related to student learning e.g. solar power stations, internet hubs had to be built in over 15 villages to ensure the devices were functional, and staff members were frequently deployed on motorcycles to collect data, repair or replace broken tablets, and update devices with new software versions. Such costs might have been avoided completely if the exact same interventions were deployed in urban areas. Interventions need to be near production ready before they are deployed in rural areas. With the infrastructural challenges of rural areas and their physical inaccessibility, there is little opportunity to gather data rapidly, prototype or beta-test multiple iterations of learning software.

Throughout our visits to families homes and interacting with residents in the village, we found that the most predominant devices used were feature phones. We did not observe any parents, except for the teachers in the private school, using smartphones. In rural areas, children often have the responsibility of contributing to upkeep of the family including fetching water, cooking, farming, taking care of animals etc. The difficulty of navigating transportation around rural areas makes students more likely to live closer to one another – we regularly ran into most students in the classrooms after school hours in the village, and teachers knew where students lived, their families etc. While there may be few adults with formal education in rural areas [157], adults in rural areas have expertise in professions that drive the local economy e.g. farming, animal rearing, and buying and selling. Therefore in unstructured rural settings, technologies that are most feasible include SMS-based and Interactive Voice Response interventions such as [112,153] deployed on feature phones. With children's other responsibilities and lack of dedicated learning devices, technology designers should expect that students may have little time to spend learning at home and may need to do so on the go. It is worth understanding culturally relevant ways of teaching and learning and taking advantage of adults and other children to provide learning support for students.

Rural schools in Tanzania face similar struggles as their urban counterparts. Class sizes are very large, and there are not enough teachers to serve all of them. All the interventions suggested for urban schools (in the next section) also apply to rural schools, however, rural schools have the additional challenge of not having the same underlying power and internet infrastructure as their urban counterparts. Therefore, while it is possible to deploy tablet-based interventions in rural areas, this cannot happen without significant infrastructural investments including and not limited to physical buildings and furnishings, power supply for all the devices, and a dedicated internet connection which may be hard to obtain if there are no cell towers in close proximity. Researchers should also bear in mind that even after providing the underlying infrastructure, it might be difficult to have schools dedicate their limited teaching staff to managing students learning and taking care of the devices. It is likely necessary to hire additional staff to coordinate technology learning programs, and advisable to design interventions where students can support one another rather than relying on a teacher or trained adult.

There are several opportunities to design technologies that are not focused on individual students learning but may provide similar learning benefits. There is a pressing need to educate students on content that produce positive economic benefits e.g. agriculture, business, and animal farming. Parents often have to grapple with the opportunity cost of their children taking time that can be spent on the family business to attend school [107]. Using technology to educate students on content that contribute positively to their family's income will likely reduce the hesitation that parents may feel about allowing their children extra time to learn using technology. Teachers in our study expressed a need for technologies that can help them automate grading, give students feedback, and distribute learning materials more effectively. Teachers also expressed the need for technologies that allow groups of students to work simultaneously under their guidance. Finally, the most attrition happens from primary schools in Tanzania after critical national examinations where students cannot proceed without passing them [138]. Educational technologies such as [153,154] specifically dedicated to students practicing for these national exams can help more students stay enrolled in school.

Education Technology Interventions in Urban Areas

Urban areas in Tanzania are densely populated, with 73% of the country's population residing in urban areas [234]. With the exponential growth of mobile phones and internet usage across Africa, there might be the assumption that these trends are similar in both rural and urban areas. However, most of the mobile infrastructure available in Tanzania is only accessible by residents in urban areas. Figure 44 shows the mobile coverage map in Tanzania (2G vs 3G vs 4G network speeds). While 2G speeds (maximum transfer speed of 384 kbit/s) are sufficient to make phone calls, it cannot reliably meet the demands of a learning system that depends on the internet to download software updates and upload usage data. The map shows that even these 2G speeds are mostly concentrated in urban areas, and higher speeds are much less accessible. Therefore, educational interventions that rely on the internet for proper function and design iteration is more likely to be successful in urban areas. Urban areas are also more likely to have access to electricity – recent reports show that only 7% of Tanzanian rural areas have regular power supply

[4]. Therefore, deploying educational interventions using devices that have the need for frequent charging (e.g. tablets with bright screens) might be impractical in rural areas except with costly investments in alternative power supply and dedicated internet connections.

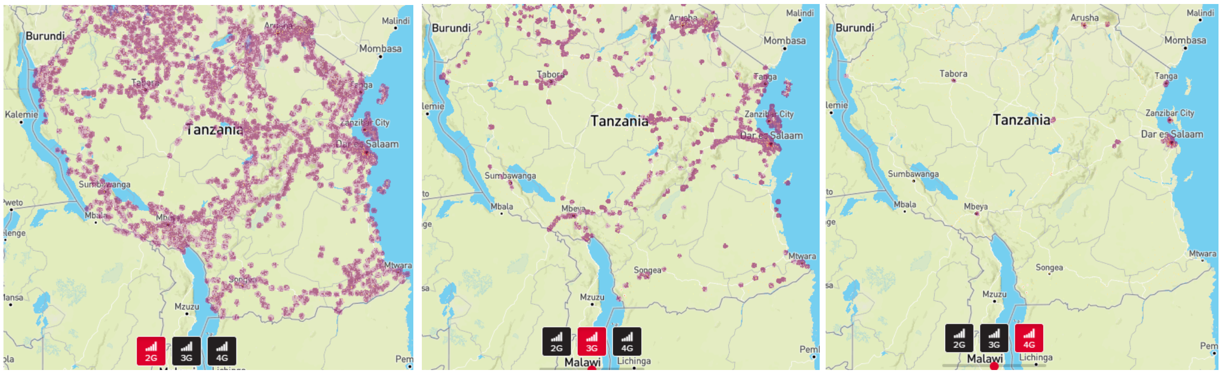

Figure 44: Mobile data coverage in Tanzania obtained from https://www.mobilecoveragemaps.com/map_tz#7/-6.249/35.021

The large population, economic vibrancy, and accessible infrastructure of urban areas in Tanzania imply that parents likely have access to smartphones with internet at home, and that parents are more likely to have a formal education. Therefore, in unstructured learning settings, smartphone-based education technologies targeted at individual students with assistance from knowledgeable adults seem more feasible. Urban areas also have less dependency on children for labor e.g. farming [107], therefore, children may have more dedicated time and space to focus on learning with technology. Students in rural areas may have to make important tradeoffs between working and learning, learn on the go, and in often noisy environments. Even with the availability of mobile infrastructure in Tanzanian urban areas, the cost of internet data is prohibitive to many families [235], therefore interventions with lower data requirements such as SMS or WhatsApp-based solutions are also worth exploring for learning in unstructured urban contexts.

Schools in urban areas face similar challenges as their rural counterparts – very large class sizes, few number of teachers, and limited schooling infrastructure such as classrooms [128]. However, the availability of power and internet services make it practical to rapidly iterate on educational interventions in a way that is impossible in rural areas. The availability of power and internet services make urban schools more ideal for deploying tablet-based educational interventions. With the shortage of teachers, students need a way to support one another while learning in these settings, therefore, help-seeking interventions (such as the system detailed in chapter 7) are likely to show success. Inside the classroom, teachers in our study were receptive to teaching using technology but insisted that it is impractical to manage with large groups of students. This presents an opportunity for researchers and educators to create learning technologies designed to be used by a group of students simultaneously, under the guidance of a teacher.

With large classes and fewer teachers, there is also the opportunity to expand educational technologies from student-centered interventions, to those that help teachers do their jobs better. Making advancements in technologies that automate grading to accommodate for children’s handwritings, low-powered audience response clickers such as [236], and technologies that allow teachers digitize teaching materials might help teachers become more effective. Finally, our results demonstrate that while teachers are open to the idea of student collaboration, they do not necessarily utilize it in ways that maximizes student learning and equally empowers high and low achieving students. Designing technologies that train teachers on more effective teaching methods while taking into account evolving government educational policies might be effective in these contexts.

Future Directions for my Research

The most immediate need for my research moving forward is to fix the application and timing related issues uncovered in the dissertation study (chapter 7), and gather data over a much longer period to evaluate the impact of my help-seeking system on learning gains. Our learning system is easily adaptable and perhaps more appropriate for urban schools so I will be looking for opportunities for collaborating with urban schools in Tanzania. I also plan to extend my work to other countries in Sub-Saharan Africa. As a native English speaker, I often felt limited in my ability to design interventions, gather feedback from students, or press on further on important topics while interviewing teachers. On several occasions, I had to remind the translators to interpret teacher responses word for word, rather than a summarized version of their question responses. Although I understood enough Swahili to understand the general message of teacher responses, I felt that I was missing the ability to probe further on specific accounts especially if I needed some background context to understand the meaning. Working in a different language also limited my ability to get to know the families and interact with the community in as much depth as I desired. Everyday after work, I walked to the village center to buy drinking water, snacks, writing supplies etc. and while I became a familiar face around town, I did not have the language ability to learn more about their lives, and living as a native in the community.

Finally, I plan to extend my work into underrepresented communities here in the United States. While learning technologies in classrooms are common in most urban schools, low income students are especially susceptible to learning losses in the summer and have less opportunity for learning in after school enrichment programs [8]. There is a great opportunity to investigate culturally appropriate ways for technology to teach subjects other than math and literacy including computer programming, engineering, art, history etc. There are distinct cultural differences between African Americans and other ethnic groups in the US [14], therefore, the skills I've gained working in diverse cultural contexts and low income communities are likely to transfer to this new research area.

8.1 Contributions

This dissertation makes several contributions to the fields of Human-Computer Interaction in developing contexts (HCI4D), Computer-Supported Collaborative Learning (CSCL), the Learning Sciences, and education in developing contexts. It tackles research questions of high relevance and worldwide interest, and directly impacts the work of educators, learning scientists, and EdTech designers who are dedicated to tackling educational inequalities in rural regions of Africa. For each listed contribution, a brief summary of the significance of the contribution with respect to prior literature is provided.

1. Understanding the effects of increased peer-peer interactions on student performance in a rural Tanzanian context
   - **Significance**: The research studies highlighted in sections 2.1.2 and 2.3.2 of this dissertation demonstrate the importance of peer-peer help-seeking both in traditional classrooms and in technology enhanced learning environments. However, most of these studies were conducted in western and urban contexts where educators already value, and students already practice beneficial helping behaviors in their learning process. Although the everyday norms and practices of our target demographic (students from rural areas in Tanzania) is one that is highly collaborative, these norms are not reflected in their classroom behaviors because teachers in this socio-cultural context do not encourage their students to collaborate independently. My research studies encourage students to collaborate with and depend on one another for their learning needs rather than depend on knowledgeable adults as is typical. The novelty of my research studies is that it provides much needed insights on the value of student collaboration in a socio-cultural context that is rarely explored and is in dire need of scalable educational interventions such as our tablet-based learning system.

2. Designing systems that specifically focus on improving tutor-tutee collaboration in low-digital literacy contexts
   - **Significance**: Research studies by [54] and others highlighted in section 2.3.3 of this dissertation document provide examples of systems that are specifically designed to improve collaboration between peers. These examples mostly focus on pre-designated groups of students in a learning system that was designed for use by more than one student at a time. The help-seeking intervention in this thesis is designed to inform learners of specific peers that can support their learning needs based on system-driven automatic detection of the errors they encounter. In addition, this system is designed to empower even struggling students to take up the role of a tutor and enjoy the psychological and cognitive benefits associated simply by mastering tasks as simple as successfully tapping through an activity.

3. Understanding the effects of introducing different pedagogical norms on a classroom culture
   - **Significance**: In section 3.1, I discuss the negative consequences of designing systems without consideration of the cultural norms of a target population. Although our learning content is developed and already validated (see [198]) for prioritizing pedagogical practices in the target culture, this dissertation attempts to highlight the effects of encouraging behaviors that are pedagogically atypical for students and teachers from that culture. Despite the number of technology initiatives that are dedicated to tackling the educational inequalities in Sub-

Saharan Africa (see section 2.3.1), there are no documented insights on the effects that these interventions have on other aspects of students' daily lives e.g. how they approach learning in their traditional classrooms. Does encouraging collaboration while learning with education technology cause students to change their behaviors in the classroom? If yes, what are the positive and negative consequences of such behavior changes?

4. Feedback models for scaffolding student interactions with learning technology
   - **Significance**: Research studies on appropriate feedback models for learning systems such as [114] discuss the benefits of the Intelligent Novice Model, prioritizing a model of desired performance over one that focuses on immediate vs delayed feedback. As with most scientific principles that involve interaction with humans, the validation of these principles in one cultural context does not necessarily mean they will be effective in another (see examples of such principles in section 3.1). My research study probes the generalizability of the Intelligent Novice Model in a different cultural context, although focusing on both human-machine and human-human interactions in a learning environment rather than just system-provided intelligent feedback. I demonstrate that although this model is effective in my target context, researchers need to have adequate timing data, and prioritize the sorts of struggles that are worth intervening for, otherwise, risk learning losses.

5. Teacher attitudes towards peer-peer collaboration in rural Tanzanian contexts

   Significance: Documented insights on the teaching practices in Tanzania (see section 2.2.4) suggest that teachers in this cultural context do not encourage student collaboration. However, there are no research studies, conducted specifically with teachers in rural Tanzanian contexts, that unpack these assumptions and investigate the reasons why teachers have these beliefs. My dissertation fills these research gaps by exploring the cultural beliefs and other factors that cause teachers preference for individual work and probes for any possible reasons that might cause teachers to become open-minded to welcoming collaborative behaviors in their classrooms.

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Appendix A – Consent Form

Ninatambua kuwa Robotutor ni kazi ya kompyuta inayosaidia watoto kujifunza kusoma, kuandikam na kuhesabu, na kuwa program hizi zinarekodi sauti na video za mtumiaji aliyekaribu ma kompyuta.

I recognize that Robotutor is a computer program that helps children learn to read, write and count, and that these programs record the audio and video of a computer user.

Ninatoa idhini kwa mtoto/watoto wangu aliyetajwa hapo chini kutumia Robotutor, na hivyo sauti yake na picha yake inaweza kuonekana sehemu nyingine kwa matumizi ya kuboresha taaluma.

I give my consent to my aforementioned child / children using Robotutor, and so his voice and image may be seen in other places for use in improving the profession.

Nimesoma fomu hii au vinginevyo nimesomewa na mta mvingine na mtu aliyetia sahihi.

I have read this form or otherwise read it by someone else who signed it.

Jina/Majina ya mtoto

Name / Names of the child

Jina la mzazi au mlezi

Name of parent or guardian

Weka sahihi au kama huwezi kusoma weka alama ya (X)

Sign here or if you cannot read mark (X)

Appendix B – Teacher Collaboration Behaviors Interview Questions

Informed consent and confidentiality:

Thanks a lot for meeting with me today. I'm conducting this interview as part of doctorate research at Carnegie Mellon in the USA. My goal is to understand your motivation for working in this school, talk about your experiences with teachers when you were a young student, and your attitude towards student collaboration in the classroom. I will submit a paper that includes analysis of your interview for my dissertation and to a conference publication, but you will remain anonymous, and we will not include your name or face in any reports. I should also mention that by participating in this interview, you're not opening yourself up to any clear risks or benefits. I do not work with or report to anyone in Tanzania so this will not affect your job in any way.

I will ask you to fill out a brief questionnaire to provide me with general context, and then we will proceed with the interview. Together, the questionnaire and interview will take about one hour.

Your participation in this study is voluntary. By completing the questionnaire and responding to my interview questions, you are voluntarily agreeing to participate. If at any point you no longer want to participate in the survey, you are free to end the session at any time. You are also free to decline to answer any particular question you do not wish to answer for any reason.

After you complete the demographic questionnaire, I plan to audio-record this interview using my recorder, and may also jot down a few notes to help me remember certain things as we talk. Are you comfortable with me recording the interview and taking notes?

Do you have any questions before we begin?

[All interview participants should fill out the demographic portion of the survey. Can be administered on paper or orally].

Demographic Questionnaire:

How long have you been a teacher in this school? How many other schools have you taught and what classes? Are you from around this area?

Interview prompts:

1. Tell me about your road to become a teacher. What schools did you attend and why did you decide to become a teacher?

2. Why did you choose to work in this school and not another, maybe in the city like Bunda, Mwanza or even Dar Es Salaam?

3. Tell me about your experiences growing up as a student. Did your teachers support students helping one another in the classroom?

4. Now you are teacher – how do you feel about students teaching and helping one another in the classroom? Good or bad? Negative or positive consequences? Should students be encouraged?

5. Are you more open to helping with certain groups of students e.g. boys vs girls, the more brilliant students in class, older vs younger children etc.?

6. Do you think that allowing students to helping one another somehow reduces your authority as a teacher?

7. Let's say the headmaster tells you that you should include collaboration activities in your classroom! In what ways are you going to try to accomplish this?

8. Would you rather have students collaborate in classroom activities or with their homework?

9. DESCRIBE RT AND GIVE THEM A DEMO

10. What about technology in the classroom … do you think this kind of technology can assist you in teaching your students?

11. Can you give me some examples of how you can possibly include technology in your teaching activities?

12. Would you prefer to use technology for support if you are teaching really large class sizes, or should be used even with small class sizes? How?

13. Should it be used on days where the teacher is not around at all or even when teachers are around?

14. Should technology be kept in the schools only, or should students be allowed to take them home for homework?

Appendix C – Baseline Test

MATH

1. Hizi ni namba gani?
    a. 2
    b. 9
    c. 0
    d. 12
    e. 22
    f. 39
    g. 108
    h. 989

2. Namba ipi kati ya hizi mbili ni kubwa Zaidi (which number is greater)?
    a. 7 or 5
    b. 21 or 14
    c. 58 or 49

3. Namba ipi kati ya hizi mbili ni ndogo Zaidi (which number is smaller)?
    a. 6 or 9
    b. 23 or 32
    c. 17 or 19

4. Unaweza kuandika nambari 1 mpaka 10 (can you write from 1-10)

5. Ni nambari gani inaweza kuwekwa katika sehemu iliyoachwa wazi (what number belongs to the blank space)?
    a. 1 2 3 __
    b. 7 6 5 __
    c. 2 4 __ 8
    d. 5 __ 15 20
    e. __ 22 33 44

6. Unajua majibu ya maswali yafuatayo (can you do these addition problems)?
    a. 1 + 3 =
    b. 6 + 2=
    c. 9 + 3 =

7. Unajua majibu ya maswali haya?
    a) 5 - 3 =

b) 12 - 5 =
c) 26 - 14 =

8. Tafadhali sikiliza maswali haya na uyajibu (listen to this story and answer the questions)

a. Kuna maembe 5 katika kikapu. Ninakula maembe matatu. Je, ni maembe mangapi yanabaki? (There are 5 mangoes in a bowl. I removed 3 mangoes. How many mangoes are left?)

b. Nina vijiti vitatu. Kaka yangu ananipa vijiti viwili zaidi. Je, sasa nina vijiti vingapi? (I have 3 sticks; my friend adds two more sticks. How many sticks do I have now?)

c. Nilikuwa na mayai. Nikampa rafiki yangu mayai mawili. Mwisho nikabakiwa na mayai matatu. Je, mwanzoni nilikuwa na mayai mangapi? (I have some eggs. My friend takes two eggs away, now I have 2 eggs left. How many eggs did I have at first?)

VERBAL

1. Je, hii ni herufi gani? (Letter identification)

a. G
b. H
c. A

2. Unasemaje neno hili? (Syllable Identification)
a. Ke
b. Tu
c. Kwe

3. Unasemaje neno hili? (Word identification)
a. Maji
b. Baba
c. Kiti

4. Unasemaje neno hili? (Word Identification)

a) Watoto
b) Rafiki
c) Chakula

5. Unaweza kuandika herufi zote kuanzia A mpaka Z? (Can you write all the letters from A-Z?)

6. Unaweza kuandika sentensi zifuatazo? (Can you write the following sentences?)
a. Fisi alitamani kula nyama

7. Unaweza kusoma aya ifuatayo? (Listen and answer the questions)

a. Mtoto mdogo anapenda kunywa maziwa. Lakini leo mama yake hana pesa ya kununulia maziwa. Sasa mtoto analia kwa sababu anataka maziwa. Mama anamwambia "nyamaza mtoto mzuri. Kesho nitapata pesa."

i. Je, mtoto anapenda nini?
ii. Kwanini mtoto Analia?
iii. Je, mama atapata pesa lini?

8. Unaweza kusoma habari ifuatayo? (can you read this sentence?)

a. Mimi ni Baraka. Nina miaka kumi. Mimi ni mwanafunzi wa shule ya msingi Mugetal. Ninapenda chapati na chai.