Speak Up: A Multi-Year Deployment of Games to Motivate Speech Therapy in India

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ABSTRACT
The ability to communicate is crucial to leading an independent life. Unfortunately, individuals from developing communities who are deaf and hard of hearing tend to encounter difficulty communicating, due to a lack of educational resources. We present findings from a two-year deployment of *Speak Up*, a suite of voice-powered games to motivate speech therapy, at a school for the deaf in India. Using ethnographic methods, we investigated the interplay between *Speak Up* and local educational practices. We found that teachers' speech therapy goals had evolved to differ from those encoded in the games, that the games influenced classroom dynamics, and that teachers had improved their computer literacy and developed creative uses for the games. We used these insights to further enhance *Speak Up* by creating an explicit teacher role in the games, making changes that encouraged teachers to build their computer literacy, and adding an embodied agent.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous; K.3.m. Computers and Education: Miscellaneous

Author Keywords
Assistive Technologies; ICTD; Ethnography; Speech Therapy; Capacity Building

INTRODUCTION
Children from developing communities who are deaf and hard of hearing (DHOH) tend to lack the resources necessary to learn to communicate beyond their support networks. Reasons for this include cultural stigmas, little opportunities for early intervention, and the lack of a standardized and socially accepted sign language. Therefore, many children who are DHOH have trouble living independent lives. Our work seeks to address this problem through a suite of voice-powered computer games that have been deployed for two-years at a school for the deaf in India. This paper explores the following questions:

- How does a long-term deployment of technology shape individual and group dynamics within an underserved community?
- How does a community's existing practices and expectations alter their usage of the technology?
- How can we incorporate knowledge of this interplay into the technology development process?

Although many computational technologies have been developed to facilitate speech therapy for individuals who are DHOH, most of these are either intended to be used by trained speech therapists [4, 11, 34, 43] or rely on expensive and sometimes inaccurate sensors and algorithms [10, 33, 38, 39]. This makes them ill-suited for developing communities, which tend to lack suitable resources and awareness about disabilities. In addition, relevant literature has investigated how educational games influence classroom dynamics and local educational practices in developing communities [12, 19]. Our work builds upon these projects by presenting findings from a long-term deployment of educational games and the subsequent enhancements we made based on those findings.

This paper presents findings from a two-year deployment of *Speak Up! Voice-Powered Game Suite* (*Speak Up*), at a school for the "deaf and differently-abled"[1] in Bengaluru, India. *Speak Up*, which was developed and deployed in 2015 at the school, is a collection of computer games to help students who are DHOH visualize and explore their voice. Two years later, we conducted follow-up fieldwork and iterated on *Speak Up*. This fieldwork revealed that the games altered classroom dynamics and were subtly misaligned with teachers' speech therapy goals. It also revealed that teachers had developed uses for the games that better aligned with their speech therapy goals. Informed by these insights, we added new features and interactions to *Speak Up*.

This paper details insights from the most recent fieldwork. It begins by describing the backdrop and design of the research, proceeds to detail how the games shaped and were shaped by social dynamics and human influences at the school, describes enhancements made to *Speak Up* based on those insights, and concludes by positioning this research in the context of relevant literature.

[1]This is the self-selected description used by the school.

CHI 2018, April 21–26, 2018, Montreal, QC, Canada

ISBN 978-1-4503-5620-6/18/04…$15.00

DOI: https://doi.org/10.1145/3173574.3173892

BACKGROUND AND RELATED WORK

Because the "majority of people with disabling hearing loss live in low- and middle-income countries" [29], they often lack adequate support and resources. For example, only 3% of developing countries' hearing aid needs are met [29]. In India, despite the Person with Disabilities Act of 1995 that prioritizes the education of individuals who are disabled [28], only about 0.5% of children who are DHOH attend a school prepared to meet their needs [42]. The deaf community in India also faces a great deal of cultural stigma, including the idea that individuals who are deaf are also "dumb." Further, speech therapists in India are scarce [40] and expensive. Lastly, sign language is not an effective option in India, due to a lack of awareness of and regional variations in the language [41, 42]. Therefore, many children who are DHOH in India do not have the resources or opportunities to learn verbal communication, although it is a prerequisite for reaching their full potential as contributing members of society.

Most research on technologies for individuals who are DHOH in developing countries focuses on tools for early assessment of hearing loss [1, 21, 24]. However, many conversational agents, games, and visualizations have been developed to support speech therapy for children with disabilities since at least the 1970s [27, 37, 44]. Many of these either rely on sophisticated and sometimes inaccurate sensors and algorithms that are not suited for long-term deployments in resource-constrained communities [10, 33, 38, 39]. Others must be used by trained speech therapists [4, 11, 34, 43]. A few tools have focused on aspects of voice that simple microphones can detect – volume modulation, continuous vocalization, and timed vocalization. These projects have shown success, including student enjoyment, ease of use, and improved student voice [3, 22]. Notably, only one of the aforementioned research projects developed a language-access tool for students from a developing country [33]; however, this tool relies on Google Speech API, which requires internet access and is therefore infeasible for many other developing communities.

There has been a growing interest in studying the ways in which: (1) educational games influence communities; and (2) existing community practices influence educational game usage. Halloluwa et al. [12] developed a touch-screen mobile application for grade 3 mathematics education in Sri Lankan schools. They found that teachers moved from a traditional, authoritative lecturer role to a more interactive and collaborative role. They also found that the application gave rise to "alpha students" and that the game influenced the spatial distribution of students in class. Lazem et al. [19] created a digital game, involving a camera that tracked individual students moving on a physical mat, to help 3rd-6th grade students in Egypt memorize multiplication tables. They found that the game increased students' recollection of the multiplication tables, that students who were not actively playing the games often got distracted, and that the games gave rise to unexpected cognitive and metacognitive strategies that students used to improve their performance. Kam et al. [16] used ethnographic methods to understand traditional games that children in India play. They found that traditional games have different game elements, goal states, and rules than Western games, which influences students' understanding of Western games. They used that knowledge to create an English literacy game that incorporates game rules and mechanics from traditional games, and found that participants learned the game faster and were more engaged by it. Lastly, Mann et al. [23] studied iPad usage in a UK classroom and found that iPads fluidly take on three roles: Friend, Functionary, and Facilitator.

RESEARCH DESIGN

This section describes the school for the deaf where we conducted our research, goes on to describe the timeline of the research and the methodologies we applied, and concludes with a description of *Speak Up* as it was before the follow-up fieldwork that is the focus of this paper.

Setting

Our local partner was the Mathru Educational Trust for the Blind[2], a non-governmental organization that was founded in 2001 by Ms. Gubbi Muktha. After an accident left her debilitated, Ms. Muktha began visiting disabilities and rehabilitation centers and saw first-hand the lack of educational resources available to children who are disabled. This inspired her to form the Trust, which runs free, residential schools for children who are blind, deaf, or have multi-sensory impairments [8, 13, 14]. Our research group has been working with the Mathru Educational Trust for over ten years [5, 15].

The site of this research project was the Mathru Centre for the Deaf and Differently-Abled (Mathru Centre). At the time of the 2017 fieldwork, the Mathru Centre enrolled 57 DHOH students (39 boys and 18 girls) from 1st-6th grade and had 5 teachers. The Mathru Centre has a high turnover of teachers – only one teacher stayed on between the 2015 deployment and our 2017 visit. The reasons for high turnover are related to socio-cultural factors. For example, many teachers at the Mathru Centre are young women who leave their jobs upon marriage due to local customs. In addition, none of the teachers are trained special educators and therefore learn while on the job – from other teachers and students. This turnover and lack of training hinders the institutional retention of best-practice information for teaching students who are DHOH. Further, best-practices for teaching speech to children who are DHOH require recurring individual sessions in quiet areas, supplemented with immersive speech experiences in students' daily routines [20, 25]. This requires time, space, and human resources that are unavailable at the Mathru Centre.

The school has a computer lab with donated desktop computers, although hardware malfunctions, OS corruption, and viruses rendered most of them nonfunctioning. The school also has two Lenovo laptops, donated by the 2015 team, that run tools developed by the team and teaching aids that teachers have since added. Teachers use the laptops during certain Computer, Speech, and Sign periods. Each of these take place 2-3 times per week. However, due to the large quantity of curricular material teachers must cover, periods frequently run over and teachers are unable to use the computers as often as expected. The unreliable electric supply and frequent computer viruses further prevents smooth usage of the laptops.

[2] http://www.mathrublindschool.org

Timeline and Research Methodology

The fieldwork presented in this paper follows a chain of research done at the Mathru Centre. In 2013 and 2015, teams spent nine-weeks conducting, amongst other research objectives, needs assessments at the school. These teams found: (1) it was difficult for new teachers to learn the job due to a lack of training materials; (2) it was time-intensive for teachers to create visual aids; and (3) it was exhausting for teachers to teach speech, due to the individualized nature of speech therapy [18, 32]. Based on this assessment, the 2015 team developed two software tools for the school: *SignBook*, a "sign language dictionary creation tool with...video and picture capturing and categorization of entries...into topics"; and *Speak Up*, "a suite of voice-powered games aimed to familiarize pre- and partially-verbal users with the power of their voice" [18]. In 2017, one researcher from our team visited for two-weeks to conduct follow-up fieldwork that investigated the ways in which *Speak Up* shaped and was shaped by the community, and use that knowledge to enhance the games. This research was two-pronged: ethnographic and technological.

The ethnographic components of the research included classroom observations, informal conversations, semi-structured interviews, and user tests and training sessions in the classroom. The conversations were frequently initiated by teachers, who wanted to know if technology could be used to solve particular pedagogical difficulties. Many of these conversations occurred in the main office, where the researcher sat in the principal's seat, a seat associated with power. The researcher was not fluent in Kannada or the school's local sign language, which combined American Sign Language, the non-standardized Indian Sign Language, and signed communications that students used at home. Therefore, all research communications with teachers were in English – sometimes involving another teacher as a translator – and all research communications with students were translated by teachers.

The technology development component of this research involved enhancing *Speak Up* based on ethnographic insights and teacher's requests. After making initial changes, we showed teachers and students the revised games and gathered their feedback. We were transparent with them about why we made the changes. Using their feedback and our observations of the user tests, we iteratively enhanced the games. Since the 2017 research trip was two-weeks long, the dual purposes of ethnographic fieldwork and iterative technology development were interwoven throughout the trip.

Ethical Considerations

Ethical concerns are of the utmost importance in interventionist ICTD research [6]. In addition to having our plan reviewed and approved by our university's IRB, we addressed this by making sure the community received tangible, desired benefits from our fieldwork. This included: using participatory methods during technology development; leaving the technology and simple documentation with multiple school affiliates; leaving the computers virus-free and with anti-virus software; and generally making ourselves available to help with any queries during and after the fieldwork. Further, in interventionist ICTD projects the researcher is implicitly endowed with a power unavailable to the community – the power to create technology. This power differential was further magnified because teachers tried to be polite and accommodating to us and were aware that we were guests of the school's founder. We attempted to minimize the impact of this power differential by not spending excessive time with any one teacher or student. Finally, to mitigate adverse risks from our frank discussion of topics such as power dynamics in this paper, we attempt to write in a neutral voice and often present direct ethnographic data rather than our interpretations of the data. We return to a discussion of ethics later in the paper.

Speak Up! Voice-Powered Game Suite

The *Speak Up! Voice-Powered Game Suite* (Figure 1) was developed by the 2015 team, at the request of and working with teachers and administrators at the school. Many students who are DHOH at the school were either unaware of the sounds their voices could make or had not been encouraged to explore those sounds. Further, teachers had trouble engaging multiple students during Speech class, due to the individualized nature of speech therapy. In response to these situations, the open-source *Speak Up* games[3] were intended to help students who are DHOH explore and understand their voice [18].

At the beginning of the 2017 fieldwork, *Speak Up* had three groups of games – Beginner Skills, Free Play, and Games – that focused on four aspects of voice – volume modulation, pitch modulation, continuous vocalizations, and timed vocalizations. These categories were decided upon based on community requests, observations of Speech classes, and the laptops' technical capabilities. *Speak Up* also included a calibration option, which listened for and subsequently ignored sounds lower than the average background volume [18].

Beginner Skills: This group contained *Volume Meter* and *Pitch Meter*. Both games display numbers and colors that correspond to student volume and pitch, respectively. These games were intended to help students visualize and learn to manipulate different aspects of their voice [18].

Free Play: This group contained generic games that teachers could use with various curricular content and speech therapy objectives. In *Fruit Tree*, student vocalization makes fruits grow larger and fall off the tree. In *Rickshaw Game*, student vocalization moves an auto-rickshaw forward, and students must continuously vocalize to crest hills. In *Fruit Basket*, student volume modulation moves a basket while fruits fall from a tree above. In *Picture That*, student vocalizations gradually make transparent pictures more opaque [18].

Games: This group contained games with explicit goals, intended to introduce friendly competition and motivate students to use their voice. In *Spaceships*, students' vocalizations shoot bullets, and students must time their sounds so the bullets hit enemies. *Drive to Mathru* is similar to *Rickshaw*, except the goal is to drive the car to the school. In *Fish Game*, student volume modulation moves the fish up and down, with the goal of avoiding obstacles for as long as possible. *Song Bird* is the same, except with pitch modulation [18].

[3] https://bitbucket.org/amalnanavati/istep-2015

Figure 1. The *Speak Up! Voice-Powered Game Suite*. From left-right, top-bottom: *Volume Meter*, *Pitch Meter*, *Fruit Tree*, *Rickshaw*, *Fruit Basket*, *Picture That*, *Spaceships*, *Drive to Mathru*, *Song Bird*, and *Fish Game*.

FINDINGS

This section details ethnographic findings from our follow-up fieldwork, focusing on the ways in which *Speak Up* both shaped and was shaped by individual and group dynamics.

Evolved Utilization of Speak Up

Categorization

Speak Up was developed to focus on four basic building-blocks of voice: volume modulation, pitch modulation, continuous vocalizations, and timed vocalizations. This was for multiple reasons. Firstly, the 2015 team wanted to develop robust, accurate, and low-cost software, and sophisticated speech recognition sensors and algorithms were either expensive or error-prone. Secondly, teachers continuously pointed out their students who mimicked lip movements but made no vocalizations. Therefore, the 2015 team focused on games that could encourage those students to vocalize. Lastly, the 2015 team theorized that in order to fully develop speech, students must first master those four constituent components of speech [18].

However, during the 2017 fieldwork, we realized that teachers' goals for speech therapy did not directly align with those encoded in the games. Specifically, teachers described their approach to speech therapy as involving a binary distinction between students who "can't speak" and those who "can try [to speak]." Both groups had large variability. Students who "can't speak" ranged from students who could only make basic vowel sounds to those who could make consonant sounds and mimic the timing of words, without integrating them into full words. Students who "can try [to speak]" ranged from students who could make multi-syllable sounds that resembled simple words to those who could speak full sentences but did not enunciate. Teachers divided games in *Speak Up* accordingly. They said that games like *Volume Meter*, *Rickshaw*, and *Fish Game* that encouraged students to "increase [their] voice" were for students who "can't speak," whereas games like *Picture That* and *Fruit Tree* that they used to encourage students to say full words were for students who "can try [to speak]."

This value mismatch was because teachers' approach to speech therapy was to have students improve upon saying whole words. Therefore, the components of speech that the *Speak Up* games focused on were only useful when tied to that larger goal, not when practiced in isolation. For example, we observed a teacher commend a student on perfecting the timing of the vocalizations involved in saying "mango;" however, although *Spaceships* also focuses on timed vocalizations, none of the teachers linked timed vocalizations in *Spaceships* to timed vocalizations in speech when describing the value of the games. This focus on whole words was related to the school's goal of teaching locally practical communication skills, as opposed to just speech skills. For students who "can't speak," this approach consisted of teaching them appropriate uses of loud and soft sounds, paired with lip reading. For students who "can try [to speak]" this consisted of teaching them to speak words that, even if not understandable in isolation, could be understood when combined with the context of the interaction.

Due to this misalignment, teachers explicitly refocused the goals of the *Speak Up* games to better match their own speech-therapy goals. *Fruit Tree* went from being a game where any vocalization grows a fruit to one where students have to say the names of specific fruits (Figure 2). *Rickshaw* went from a game where students continuously vocalize to one where students say the names of everyday objects in order to move the vehicle forward. Although teachers did not explicitly focus on the components of voice that the games did, there were indications that students were improving their ability to utilize those specific components of voice. In 2015, we observed one student repeatedly mimic her teacher's lip movements but not make any sounds. In 2017, she could both modulate the volume of her voice and time her vocalizations to match the cadence of a word. However, she was unable to integrate those skills to say whole words, and teachers still put her in the category of students who "can't speak." It will take further fieldwork to understand the long-term effects of technological tools that incorporate two different value systems: one which breaks speech down into constituent vocal skills (the researchers' outlook), and one which focuses on speaking words in their entirety (the community's outlook).

Perceptions of Speak Up

Teachers' perceptions of *Speak Up* created disconnects between how the games were intended to be used and how they were used. For example, we repeatedly observed teachers explaining to students and other teachers that loud vocalizations made the rickshaw in *Rickshaw* move faster. It did not

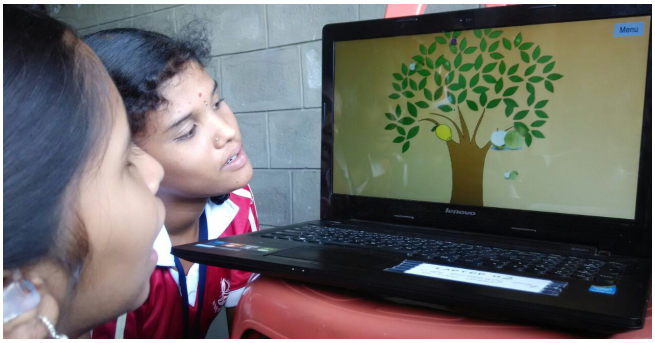

Figure 2. Students say the names of fruit as they fall down in *Fruit Tree*. (Picture courtesy of the Mathru Centre).

matter that the rickshaw always moved at the same speed – once students were taught that vocalizing loudly would give them the reward of speed, they screamed while using the game. Even when students realized that the games worked differently than the teacher described and began using them that way – for example, ceasing to vocalize on downhills so the rickshaw could roll by itself – they were chastised by their teachers and forced to use the games in ways that aligned with teachers' perceptions. This not only resulted in game usage that was unexpected, but also in game usage that teachers did not always find valuable (having students scream until their throat hurts). Despite this, teachers did not question the games or try to find alternate uses for them.

In other cases, teachers' perceptions of the utility of the games differed from how they actually used them. Whenever they trained other teachers, teachers would say *Volume Meter* is useful for teaching students "soft voice [and] loud voice." However, when they used it in class, *Volume Meter* became a game about getting the highest score on the meter as possible – not a difficult task since students could move arbitrarily close to the microphone. In this scenario, teachers and students' desire for competition and their interpretation of the meter readings as a score prevented them from using the games in a way that aligned with teachers' perceived value of the games.

Classroom Power Dynamics

Teacher-Student Dynamics

There was a culturally-influenced power dynamic in most classes, where students were expected to not challenge the authority of teachers. Therefore, in Speech and other classes without the laptops, we observed teachers dictating what was done in class – what activities students worked on, which students should answer questions, and when students were correct or wrong. Teachers frequently used this power to act as gatekeepers; when many students were excited to take part in an activity, such as spelling a word in front of the class, the teacher would decide who was allowed to do so.

However, the introduction of technology caused a shift in this power dynamic since older students knew more about the technology than teachers did. These students were quick to correct teachers – with arm gestures or vocalizations – when teachers made typos or clicked a wrong button. After being corrected by students multiple times, teachers ceded control of the computer to students, with an arm gesture indicating 'you do it.' These teachers subsequently minimized their interventions in the student operation of the games. Earlier, they would position themselves close to the computer, telling students when to speak and when to be silent and demonstrating how to make particular vocalizations. After ceding control, the same teachers moved away from the computer, allowing students to decide what games to use next, and ceased their prior speech therapy guidance as to how students should use the games.

This was not the case in lower grade levels where students had fewer computer skills. In these classes, teachers maintained control of the laptops and used their gatekeeper position to choose which students used the games and to instruct them in how to use the games – similar to the power dynamic we observed in classes without the laptop. In addition to the grade level and computer literacy of students, other factors that may have influenced teachers' behavior of ceding control of the games were the age of teachers and how long they had been at the school. We observed that younger teachers and newer teachers tended to cede control of the games more frequently than older, more experienced teachers.

Student-Student Dynamics

Before the games were introduced during the 2015 fieldwork, teachers went to each student one-by-one in Speech class to give speech therapy instruction [18]. In 2017, they had organically adopted a practice of selectively focusing on specific students for each game based on student skill level (i.e. focusing on students who "can speak" for games like *Picture That*). This gave rise to a hierarchy amongst students during Speech class. This hierarchy was influenced by how much the students knew about operating the computer, how good the students were at the games, and whether teachers characterized the student as one who "can speak" or "can try [to speak]." These factors were not mutually exclusive – frequently, students with better hearing or vocal capabilities (who were more likely to be characterized as students who "can speak") would better understand the games, hence be given more time with the computer, and therefore increase their computer literacy.

Higher tier students were more likely to be picked by teachers to demonstrate the usage of particular games. They also invariably ended up at the focal point of computer use without teacher prompting: by moving closer to the computer, taking an active role in playing more games than their peers, and taking control of the operation of the computer. In classes where teachers maintained more authority over the class, some teachers channeled this hierarchy to achieve positive outcomes by instructing higher tier students to teach other students how to use the games. However, in classes where teachers maintained less authority, students who were higher in this hierarchy tended to co-opt the entire interaction with the computer from other students. One such student would non-maliciously make himself the sole person who controlled the keyboard and mouse, and another such student would yell loudly to demonstrate his prowess at the games and to drown out other student voices. All such higher tier students were male.

Changes in Classroom Behavior

In all grade levels, a periodic ebb and flow between collective and individual usage of the games emerged whenever teachers brought the games in front of the class. Especially with older students who were familiar with the games, they would all start using the games at once – moving to stand in front of the games and collectively OOH-ing, for example, to move the rickshaw forward. The teacher would then quiet them down, and tell just one student to use the games. The class would remain silent for much of the time that student was playing the game, with the occasional student making vocalizations and then glancing at the teacher, to gauge her response. However, after the student who was using the game finished, we observed other students vying for the opportunity to go next. In certain games such as *Picture That* and *Fruit Tree*, teachers were more accommodating of a collective usage of the games, since the games' functionality and engagement value did not depend on individual use. In such cases, we saw the teacher focusing on giving feedback to one student, but also working with other students who were trying to use the games. In other games such as *Fish Game*, where differing intentions amongst students caused some to vocalize loudly and some to vocalize softly, teachers would only allow one person to play the game at once, so the microphone could pick up on that student's volume modulation.

This periodic ebb-and-flow mimicked group dynamics that occurred during other classroom activities involving one student in the spotlight. For example, a similar dynamic emerged when teachers drew objects on the blackboard and asked students to spell, sign, or say the names of those objects. In such cases, students would raise their hands, make vocalizations, or begin answering the question in order to get the teacher to pick them. However, this ebb-and-flow between collective and individual engagement differed significantly from the dynamic that the 2015 team observed in Speech classes. In those classes, the teachers focused on teaching one student to say a particular word or sound, while other students stayed silent or got distracted [18]. Therefore, *Speak Up* contributed to altering the group dynamics of Speech class to match those of students' other classes, which aligns with the teachers' original goal for the games to engage students during speech therapy.

Familiarity with Technology

When the 2015 team arrived at the school, teachers had little to no grasp of computers' capacity to support their work [18]. However, when our team arrived in 2017, teachers were not only familiar with the games, but they were also familiar enough with the capabilities of computers to imagine and suggest other feasible games to add. In fact, one teacher repeatedly asked us whether we could teach her how to make the games, so she would not have to wait for us to visit. In addition, teachers had developed dynamic and creative uses for the technological tools. Upon realizing that the *Rickshaw* game was too easy for one student, a teacher made him say the names of everyday objects – instead of AAHs and OOHs – in order to move the car. Another teacher asked us how she could add pictures to tailor *Picture That* to her curriculum, and yet another teacher had begun using *SignBook* to store and playback whole stories (instead of individual vocabulary words as we had intended). In addition, teachers' computer skills (operating the keyboard and mouse, turning on/off the computer, opening applications, etc.) had improved since 2015. Since every teacher but one was new, it is difficult to attribute this increase in computer literacy to our games. However, most teachers did not have access to a computer outside of the school, and the one teacher who had been at the school since 2015 had dramatically increased her computer literacy and creative uses of the technology.

In addition to teacher skill improvements, students' familiarity with computers had also increased. Students that we saw operating the computers (many, but not all, of whom were higher in the hierarchy) were more familiar with the keyboard, mouse, and computer icons than they had been in 2015. In fact, one student would even use touchpad gestures to play pranks on the teacher, by making windows disappear and reappear. In addition to computer literacy, one student had even learned troubleshooting skills. When *Speak Up* was malfunctioning, she looked up, noticed the fan was on (and therefore creating background noise) and turned it off. This increased familiarity with technology is in accordance with changes seen in our other projects at the Mathru Educational Trust [5, 7].

ENHANCEMENTS TO SPEAK UP

This section details the improvements we made to *Speak Up* based on the ethnographic insights above.

Utilizing Teacher Expertise

Based on teachers' categorization of the games, they felt that most *Speak Up* games were for students who "can't speak." As a result, they wanted more games for students who "can try [to speak]." Based on their descriptions, this entailed having quiz modes, where the computer grades and provides feedback to students based on their pronunciation of words. Unfortunately, due to the probabilistic nature of most modern speech recognition systems and the inaccuracies of phoneme recognition [2, 9, 35], this was not possible. Having a computer understand the phonemes and words made by pre-verbal individuals, especially in developing communities where there is a wide variability in speech capabilities, is beyond the technological state-of-the-art. However, this gave us the opportunity to explicitly incorporate teachers' expertise into *Speak Up*, by adding quiz modes to *Picture That* that, instead of having the computer grade student pronunciation, had teachers press the 'r' or 'w' keys to tell the computer whether the pronunciation was right or wrong, respectively.

We intended for this change to give teachers an explicit gatekeeper role in the games, thereby restoring classroom power dynamics during Speech class to that of other classes. Yet, unsurprisingly this was teacher-dependent. Some teachers still ceded control of how *Speak Up* was used to their students, by allowing them to press 'r' to merely advance the games. Others saw a pedagogical purpose in grading students right or wrong and therefore maintained their gatekeeper position, creating a classroom environment in which students strove to get an 'r.' For those teachers, this change allowed them to dynamically respond to collective and individual usages of the games. They could filter through multiple student voices to

focus on an individual, change that focus to other students as desired, and modify the difficulty level or type of questions based on individual students. These were all strategies they employed in other classes, but could not employ with the old version of *Speak Up* that operated autonomously. Therefore, making *Speak Up* more similar to existing teaching aides that teachers employed, such as a drawing images on a blackboard, encouraged them to utilize familiar pedagogical strategies.

Adapting to the Community's Context

After observing the disconnect between teachers' beliefs about the games versus how they really worked, we adapted some games to better align with teachers' perceptions. For example, we changed the *Rickshaw* game such that louder voice truly moves the rickshaw faster, and added an explicit volume modulation component to *Volume Meter*. In the case of *Rickshaw*, we felt that this change did not alter the original goal of the game – continuous vocalization – but rather made the game easier for teachers to use and train others on. In the case of *Volume Meter*, the new version requires students to maintain their voice at a particular volume level in order to get stars, rather than to vocalize as loudly as possible. This channeled students' motivation to get a high score into modulating their volume, which was teachers' stated goal for the game.

However, we felt that some games would be more beneficial to students if used in a way that aligned with our original goals, and discussed this sentiment with teachers. For example, students continuously vocalized while playing *Spaceships*, in order to shoot as many bullets as possible. Yet, multiple games focused on continuous vocalizations, and only *Spaceships* involved timed vocalizations. Therefore, we modified *Spaceships* to detect spikes in volume before shooting a bullet. Although the idea for this change did not come from teachers, they quickly found new pedagogical purposes for *Spaceships*, such as having students say the ABCs to shoot bullets.

We also adapted the games to fit the Mathru Centre's environmental context. The school is an open-air campus and has constant background noise: birds chirping, religious hymns from nearby places of worship, and the sound of the gardener mowing the lawn. This makes it nearly impossible for laptops to detect soft voices – which are required in games like *Fish Game* and *Fruit Basket* – because they become drowned out by background noise. Therefore, we added a modality to those games in which arrow keys control the direction of motion and volume controls the speed. This retained the focus on volume modulation while allowing students to successfully move the character in both directions. This change also decoupled the direction and speed of the game's main character, giving users more control. With younger students, teachers used the arrow keys to select a direction and students provided the voice. With older students, teachers allowed them to fully operate the games, which teachers said increased students' familiarity with computers. Lastly, this change made the games more conducive to collective usage. Earlier, only one student could vocalize at a time in order for the laptop to parse their volume and determine their intended direction. Now, one student could control the direction of the character and multiple students could vocalize to determine its speed.

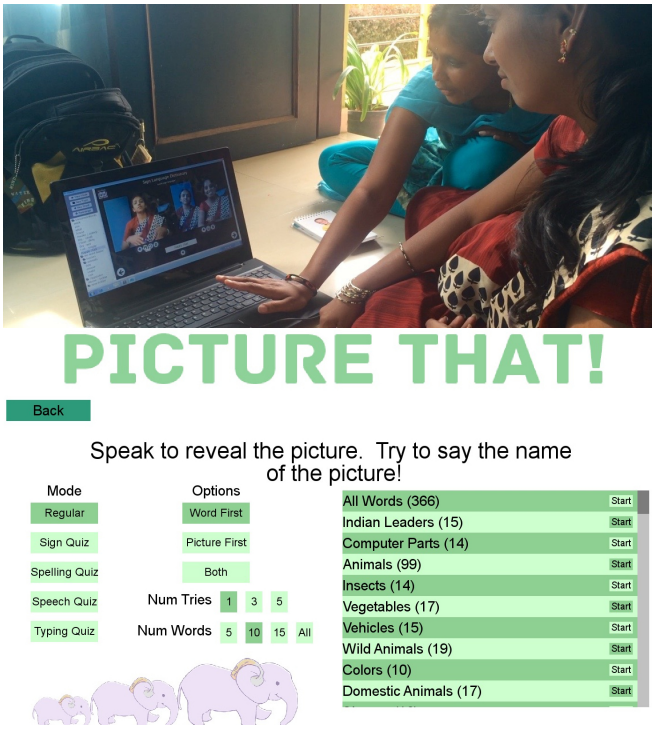

Figure 3. Top: Teachers adding entries to *SignBook* in 2015. Bottom: The new *Picture That* menu, which imports *SignBook* images.

Lastly, we adapted many games to teachers' views of what would motivate students – namely, competition. Therefore, we added high score tracking to games with explicit end goals – *Fruit Basket*, *Spaceships*, *Drive to Mathru*, *Fish Game*, and *Song Bird*. We specifically did not add high scores to open-ended games, such as *Rickshaw*, *Pitch Meter*, and the original *Volume Meter*, for fear that high scores would rigidify possible usages of the games. These changes helped motivate students – more students were clamoring to use games with high scores and some teachers kept track of student scores across classes. However, the changes also shifted the games to a more individual usage. Most teachers encouraged other students to remain silent while one student used the games, and one teacher even requested an additional time limit to be placed on the games so multiple students could get a chance to play individually. This illustrates the unintentional byproduct on group dynamics that even small technological changes can have. Informed by this insight, we left original versions of all games in case teachers wanted to use them in different contexts.

Customizability

Amongst the teachers' requests for additions to the games, they repeatedly mentioned the need for more games with curriculum-specific content. For example, they suggested a game that shows a hospital, and students have to say the names of professional people found in the hospital. We recognized that any curriculum-specific games we developed would soon lose their usefulness due to vastly different curricular needs per grade level. Therefore, we decided to create a system for teachers to add their own pictures to *Picture That*. A simi-

lar system had been implemented in 2015, in which teachers would take a picture using third-party webcam software and drag it into a folder specifically for *Picture That* images [18]. However, by 2017 all teachers had forgotten how to use that feature, likely due to the complicated multi-step process that involved familiarity with the computer's file system.

In this revision, we utilized webcam software that teachers were already familiar with: *SignBook*, a sign language documentation tool developed by the 2015 team. We modified *Speak Up* so any pictures, words, or folders added to *SignBook* were automatically copied into *Speak Up*'s folder (Figure 3). This way, there were minimal dependencies between the tools; if *SignBook* failed or got corrupted, *Speak Up* would still have a local copy of all its pictures. We trained teachers on how to utilize this integration, and they trained other teachers. However, it will take further fieldwork to determine if this integration is sustainable and effectively responds to teachers' requests for customizability.

Embodied Agents as Extensions to Speak Up

In addition to the aforementioned enhancements, the 2017 fieldwork also included an investigation of the potential for non-screen visual feedback to enhance *Speak Up*. Prior work has revealed the potential for embodied physical agents to improve learning outcomes amongst children who are DHOH [20, 30]. To investigate the potential for such agents to enhance *Speak Up*, we developed an Arduino-based wireless car and two corresponding games. In *Robotic Car Basic Game*, the computer's arrow keys set a direction for the car and student vocalization makes it move. In *Robotic Car Stop-and-Go*, students need to say, sign, or spell the name of a picture, verified by a teacher pressing 'r' or 'w,' in order to move the car. We made the basic game to demonstrate to teachers the capabilities of the car. In response to their concerns that it was just a game and had no pedagogical value, we brainstormed extensions with them, resulting in the stop-and-go game.

The car altered the spatial distribution of students in the classroom. It separated the focus of engagement (the car) from the focus of learning (the computer and teacher). Many students chased after the car, keeping them engaged while the teacher focused on the student who was vocalizing at the computer (Figure 4). Further, navigating the car became a collaborative activity. As the teacher or student at the computer navigated the car, other students formed bridges for the car to go under, jumped away if the car approached them, or moved the car if it got stuck. One teacher used the arrow keys in the basic game as a reward mechanism – she would only press the keys when the student made the sounds she requested, thereby creating the illusion that the computer approved of the student's sound. Lastly, there was an age-component to the car. While young students were enthralled by it and stayed engaged for long periods of time, older students quickly got bored and even started playing pranks with the car, such as hiding it.

Focusing on Capacity Building

An underlying theme in our enhancements to *Speak Up* was the importance of capacity building amongst community members. Although the original goal of *Speak Up* was to help students explore, understand, and practice their voice and to keep students engaged in Speech class, *Speak Up* was having a more sustainable impact by building computer literacy and empowering teachers to find creative uses of the technology. This observation led us to re-conceptualize the goals of *Speak Up*. We began explicitly focusing on changes that built teachers' problem-solving skills, computer literacy, and familiarity with technology. As evidenced by the 2015 picture-adding feature that teachers did not use, it was clear that the games could not jump too far ahead of teacher's current computer skills. Therefore, we decided to make changes that built on and furthered improvements we had seen in teacher capacity between 2015 and 2017. Incorporating arrow key control to *Fish Game*, *Fruit Basket*, and the robotic car games did not just increase usability. It was also an effort to increase teachers' familiarity with the keyboard, and could not have been implemented in 2015 due to teachers' unfamiliarity with computers. By having teachers press 'r' or 'w' to tell the computer whether students were right or wrong, we moved *Picture That* away from a specific tool to a more generic framework. That change, coupled with the integration between *Speak Up* and *SignBook*, allowed teachers to create custom quizzes; they took pictures in *SignBook*, imported them into *Speak Up*, and asked their own custom questions during class. Lastly, one of the reasons for introducing the robotic car was presenting teachers with new possibilities for the potential of technology, which may grow into ideas for the future.

Figure 4. A teacher (right, off-screen) uses arrow keys to control the direction of the car (circled) while a student (in front of the computer) propels the car with his voice. Other students (left) remain engaged by following the car.

DISCUSSION

This section reflects on some of the methodologies we employed over the course of the research, and then positions this research in the context of relevant literature.

Methodological Reflections

Institutional Memory

Institutional retention of information is crucial for schools like Mathru, with high teacher turnover. Although teacher training is one way to achieve retention of information, it is not perfect. Over time teachers forgot how to use the games (the fact that we had provided instruction guides in 2015 had slipped out of institutional memory) and the high turnover meant that teacher trainings were often led by teachers who had themselves been at the school a short time. However, students

were a crucial asset for institutional retention of information. Not only did they know how the games worked, they frequently knew it better than teachers. Even if some students forgot, the collaborative dynamic that emerged when they used the games resulted in them rapidly remembering. This mandated broadening the scope of training, to train both students and teachers. Neither students nor teachers were the sole users of the games – rather, they were partners whose crucial role in the community we had to recognize and whom we had to work with in order to ensure the sustainability of the games.

Navigating Researcher-Community Power Differentials

There was a power differential between our team and members of the school community, due to the cultural norm of being hospitable to respected guests. This made it near-impossible for the team to observe authentic, unobstructed uses of the games. Whenever we asked teachers when they would use *Speak Up*, they said, "Right now;" not because they had intended to use it, but because they wanted to accommodate us and were eager to demonstrate their familiarity with the games. However, there were some unique benefits to these orchestrated observations. No one was maintaining the façade that we were not affecting the observation. This shared understanding lowered the barrier between the observer and the observed, allowing us to participate in the interaction. If teachers were confused about any aspect of the games, they would ask us immediately. If we wanted to focus their attention on a particular new feature or game, we would ask them to. However, as soon as we had provided the needed information, we stepped back and observed the teacher using the games. In the 2015 deployment, observations were chiefly used for the iterative technology development process and separate teacher trainings occurred outside of the classroom. Conversely, the 2017 process was more participatory – we trained teachers on the games (even if they were still prototypes) while gathering observations and feedback to improve them. This allowed us to provide more in-depth training and give the teachers a deeper understanding of the ups, downs, and uncertainties of the technology development process.

Usage Logs as an Ethnographic Method

Foreseeing that many factors would likely contribute to prevent researchers from gathering authentic accounts of game usage, the 2015 team added a usage log to *Speak Up*. This log automatically stored the date and games played whenever teachers used *Speak Up*. This turned out to be useful. During our 2017 fieldwork, teachers said they used *Speak Up* twice a week, but the usage log indicated that they used it once every 2-4 weeks. This raised the question of what we should do with this information.

We opted to tell the teachers about the usage log. They revealed that they used the games infrequently because they had been trained in what the games were, but not how to use them in a classroom. Further, cultural context likely played a role in teachers' saying the games were frequently used; teachers often tried to be polite and express appreciation for our work. In this research, there is currently no indication that revealing the existence of the usage log affected teachers' use of the games. However, this does not make usage logs an appropriate methodology for all community-centric technology projects. This method is rife with questions of privacy, power, policing, and technology's role in shaping community behaviors.

Positioning Our Work Within Relevant Literature

Changes to Classroom Dynamics

Halloluwa et al.'s [12] work on a tablet game to teach grade 3 mathematics in Sri Lankan schools explored technology-influenced changes in classroom power dynamics . They noticed the rise of "alpha students," who understood the game faster than other students. We noticed the rise of a similar hierarchy amongst students, and extend this insight by presenting factors that influenced the rise of this hierarchy (student hearing, speaking, and computer skills). Further, they noticed that "alpha students" tended to help other students understand the game; we found that this was not always the case, and whether higher tier students helped or not depended on how much control the teacher maintained over computer usage. Halloluwa et al. also noticed that the introduction of the game led to a more interactive class, where teachers walked around and helped students more. We found a similar reduction in the traditional authority of teachers, but this came along with ceding complete control over how the games were used. One factor that accounts for this difference is that Halloluwa et al.'s game was intended to both engage and teach students, and therefore had an implicit role for teachers – to support the teaching. On the other hand, *Speak Up* was primarily intended to engage students, and the teaching had to be provided by teachers. This left a lot of flexibility for what role the teacher could play. However, when we added an explicit role for teachers in *Picture That*, we noticed that teachers took a more active role in student learning, as in Halloluwa et al.'s work.

In addition to power dynamics, a few works have discussed technology-influenced changes in student behavior. Halloluwa et al. [12] found that students often rearranged their desks from rows facing the front into circles, so they could collaborate while using the games . We saw a similar shift in spatial distribution when the laptop was brought in front of a class and all students would move to stand in front of it. Similarly, Lazem et al. [19] found that when students were not playing the multiplication game, they would often get distracted. We saw this behavior before the games were introduced in 2015 – other students would get distracted while the teacher focused on individual students for speech therapy – but not after the games were introduced. One factor that accounts for this difference is that only one student could play Lazem et al.'s game at a time, whereas multiple students could play the *Speak Up* games at once. This highlight the importance of developing games for individual use (to maximize specific students' learning outcomes) as well as collective use (to engage as many students as possible). Lastly, Mann et al. [23] found that iPads fluidly moved between the role of students' friends (Friend), a facilitator of non-technical classroom activities (Functionary), and the focus of technical classroom activities (Facilitator). At Mathru, we found that the laptops always played the Functionary role. This was partly by the design of *Speak Up*, but also because Mathru does not have the ubiquity of technology or baseline student computer literacy to enable technology to take on the other two roles.

Unanticipated Utilization of Technology

A few works also investigate unanticipated uses and outcomes of educational games for children in developing communities. Lazem et al. [19] found that students adopted unexpected policies to improve their individual and team performance at the multiplication game, such as mildly punishing each other for getting a wrong answer or creating index cards to practice multiplication before using the games. We also found unexpected usages emerging, but by teachers as opposed to students (i.e. teachers using the new *Picture That* to make custom quizzes). This difference can be accounted for by the fact that the students at Mathru could not improve upon their speech by themselves due to an inability to get feedback, and the fact that teachers had more flexibility when deciding how students used the games than students had when using the games. Similarly, Kam et al. [16] found that children in India had trouble understanding certain rules of Western mobile phone games, due to the different goals and game mechanics between Western games and traditional games. We found a similar disconnect in expectations versus reality when teachers believed that louder voice moves the rickshaw faster. Interestingly, the *Speak Up* games align with some of the traditional game goals and rule mechanics identified by Kam et al., such as minimizing/maximizing time, maximizing a variable, evading an object, and reaching a destination. This was not intentional, and arose organically out of the participatory methods used to design the games.

Capacity Building

Capacity building and empowerment – "the process through which individuals, organizations and societies obtain, strengthen and maintain the capabilities to set and achieve their own development objectives over time" [31] – has been a growing focus of ICTD research [17, 26, 36]. However, many of these projects focus on the potential for static technologies to build capacity. In this paper, we extend that focus to investigate ways of further building capacity through iterative fieldwork. In our follow-up fieldwork, we intentionally modified *Speak Up* to not only fulfill teachers' requests, but also build students and teachers' problem-solving skills, computer literacy, and familiarity with technology. We hoped that by evaluating teachers' familiarity with technology every time we visit and modifying the games to encourage them to use additional aspects of the computer, teachers would gradually become more comfortable and confident with operating computers. In this way, capacity building moved from a goal encoded in our technology to a goal encoded in our methodology; *Speak Up* was no longer simply a tool that fulfilled particular pedagogical needs, but also part of an iterative process to encourage teachers to gain confidence with additional aspects of technology.

However, just developing technological tools with an eye towards capacity building is not enough; our goal was to build capacities that moved beyond *Speak Up* usage. When training teachers on how to use *Speak Up*, we explicitly encouraged them to utilize the games as they saw fit. When the robotic car stopped working in class, we showed teachers how to troubleshoot it. This focus on capacity building also transcended technology. When teachers asked us how to solve pedagogical difficulties they faced, we brainstormed with them, highlighting our thought process when solving unfamiliar problems. Our current and past research projects with the Mathru Educational Trust indicate positive outcomes from such techniques. However, it will take systematic and long-term follow-up research to investigate the impacts of this focus on capacity building, and how it affects problem-solving skills, computer literacy, and familiarity with technology.

CONCLUSION

In this paper, we described ethnographic insights generated from two-weeks of fieldwork in an Indian school for children who are DHOH and our simultaneous technology iteration on the *Speak Up* games. This paper documents the unexpected ways in which *Speak Up* was used and influenced classroom dynamics, and how we incorporated those insights into the technology development process. It demonstrates the need for and documents a case study of explicitly making capacity building the focus of technology development for underserved communities. Lastly, it introduces initial findings regarding the potential for embodied physical agents to enhance educational technologies for children in resource-constrained settings.

There are a few notable limitations of this research. First, the power differential and language barrier between the researcher and the community hindered our ability to get accurate information about the game usage. Secondly, the novelty aspect may have influenced how students used *Speak Up* – although they had used the games for two years, the presence of a researcher from America likely made them more excited than usual to use the games. Lastly, the timeline of this research – the fact that it consisted of two fieldwork visits two years apart – hindered our ability to get accurate information about and support the teachers in their game usage during the interim.

This work opens exciting avenues for future research. On the ethnographic front, it motivates follow-up directions of study including: what the long-term effects of the hierarchy that develops in Speech class are; how long-term usage of the embodied physical agent impacts classroom dynamics; and how students think about and perceive value in *Speak Up*. On the technological front, it prompts further work on speech recognition to understand student pronunciation; one way to ensure that such research is community-centric is by using the existing games to record anonymized voice data that then informs the design of a speech recognition system. Lastly, on the capacity building front, this work motivates further research into how to measure the impact of capacity building in ICTD research, both within technological tools and in more general interactions between researchers and the community.

ACKNOWLEDGMENTS

Sincerest thanks to the Mathru Educational Trust for the Blind and Ms. Gubbi Muktha, without whom this research would not have been possible. Further thanks to IEEE RAS-SIGHT for generously funding this project and the reviewers for providing very helpful feedback. Many thanks to Xiang Zhi Tan and Cecilia Morales for their help creating the robotic car, and our family and friends for their help editing this paper.

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