Conceptual Learning through Accessible Play: Project Torino and Computational Thinking for Blind Children in India

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ABSTRACT

Project Torino is a physical programming environment designed for teaching computational thinking to children in schools in the UK, regardless of the level of vision. We introduced project Torino to children in three schools for the blind in Bangalore, India as a toy for playing with songs, rhymes, and stories. We present the results of 103 semi-structured play sessions spread over three months with 12 children (2 girls, 10 boys) with diverse backgrounds. We found that children progressed from playing with pre-connected examples, to making changes, to actively participating in what items are played. Engaging the children in conversation while they played, we established that the teams had grasped three basic concepts of computational thinking–flow of control, variables, and loops without any explicit instructions towards learning them. We propose that play-based approaches can be successfully used with low resource overhead to introduce fundamental concepts of computational thinking.

CCS CONCEPTS

• **Human-centered computing → User studies**; **HCI theory, concepts and models**; **Accessibility design and evaluation methods**.

KEYWORDS

User Experience Design; Education/Learning; Empirical study that tells us about how people use a system; Individuals with Disabilities & Assistive Technologies

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1 INTRODUCTION

Learning computing could be transformative for people who are blind or low vision, just as it is true for sighted persons. It is increasingly a common skill among young people, and can also have important long-term professional outcomes, as is reflected in numerous efforts on digital skilling for the blind [14, 24, 28]. A foundational requirement for this is introducing children to Computational Thinking (CT) [41] at an early age. Many countries, including the UK, have made computing a part of their regular curriculum starting at the primary grades [8, 9, 11, 16, 33], and there are corresponding efforts to introduce CT skills to children who are blind or low vision [15, 18, 34].

Children who are blind or low vision face serious challenges in acquiring a quality education in India, home to the largest number of people who are blind or low vision in the world [7], who also occupy the lowest socio-economic strata and are denied numerous opportunities [19, 30]. A vast majority of children who are blind or low vision attend, if at all they are able to, schools for the blind that have the following characteristics: There is a shortage of teachers resulting in children from multiple grades often being grouped into one class. Teachers teach multiple subjects, and many are themselves blind. There are insufficient resources including lab resources and there are hardly any trained special educators. There is a wide variance in the age of children in the same grade since many parents find out about the availability of schooling for the blind fairly late. These factors have resulted in a vast majority of such children being denied STEM education beyond middle school across the country.

In contrast, the STEM opportunities for the general population in India has exponentially increased in the past two to three decades. By some accounts, India has the third largest pool of science and technology manpower in the world [3], with hardly any representation from people with vision impairments. Our work is motivated by the fact that without early intervention, children with vision impairments may be locked out of wide range of opportunities that require computational thinking.

There are efforts underway to incorporate computational thinking into the school curriculum in India, starting at grade 1 and to give it the same importance as the other basic skills in school

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education. A curriculum for CT has been recently created under the aegis of ACM India [10]. However, it is directed at sighted children and the content and resources are unsuitable for teachers and students who are blind. There is no initiative that we are aware of that addresses the need to include children who are blind or of low vision in efforts to introduce computational thinking at the primary school level. Our research is motivated by the objective of enabling children who are blind or low vision to learn computing at the same stage as sighted children.

For this, some of the foundational concepts of computational thinking need to be made accessible and learnable at the primary school level for such children.

Many of the tools built to include computation to people who are blind have focused on making traditional programming languages and environments accessible via screen reader (see [32] and references therein), usually to older individuals who have picked up computing skills. Computational thinking has been primarily introduced to sighted children using many of the visual and block-based programming environments like Scratch [5] or Alice [12]. However, recognizing the limitations of such environments for children who are blind or low vision, there have been efforts to create tangible or physical programming environments [21, 25, 27, 35, 38, 42]. While these technologies have been designed for high resource settings, there has been no previous published work exploring their relevance and usage in a low resource environments. We zeroed in on Torino Learning Environment (Torino) ([29], [37]), a physical programming environment developed at Microsoft Research. Torino has been successfully evaluated at scale in schools in the UK to teach the Computational Thinking curriculum. In their work, they have grounded their theoretical approach on [41], who introduced the term computational learning to define CT in the school learning environments. Torino has since been released as a commercial product, CodeJumper, by American Publishing House [13]. For this study, we obtained three such kits for the school children to use. The technical and operational details of Torino along with a description of how it was deployed and evaluated in the UK are presented in Section 3.

The ground reality of schools for the blind in India (as described in Section 2) is diametrically different from that in the UK. These differences include a considerably large number of children who are blind and low vision, substantially limited resources in terms of infrastructure, and most importantly, very limited number of trained teachers. In our research, we use a methodology centered around play and playfulness for overcoming these limitations. The key implication of this approach is that we introduce Torino as a toy for creative exploration of music, sounds and storytelling, rather than as a device for computational thinking. The rest of the paper describes our study that sets out to answer the following research question.

Research Question: Is it possible for children who are blind, studying in schools for the blind in low-resource settings, to pick up concepts in computational thinking using Project Torino with reliance on play instead of structured teaching.

The specific computational thinking concepts are from [31] and are the same as used by the Project Torino Study: Computational concepts(sequence, thread, loop and if-then-else), Computational practice(tracing and debugging) and Computational perspectives (expressing and connecting).

2 CHALLENGES IN SCHOOLING FOR THE BLIND IN INDIA

There is a paucity of reliable data on all aspects of children with vision impairment and their schooling. The most cited official document is the 2011 Census reported by the Government of India that estimates the number of individuals who are 'disabled in seeing'[1, 6] to be about 700,000 in the age group 0 to 9 and another 900,000 in the age group 10-19. India is also a signatory to the UNCRPD [2] and has also enacted a national law on the rights of people with disabilities [40]. There is also to a Right to Education law[39] that provides education as a constitutional right to every citizen of the country. However, the impact on the ground is minimal. Estimates on the number of children in the above group who attend school are hard to come by, but non-profit groups operating in the area report that fewer than 50% currently attend school.

Among these, a vast majority attend schools for the blind for their primary education. An estimate from the National Association for the Blind, a non-profit, pegs the number of children attending integrated schools to be less than 1000 in the entire country.

Given the difficulties faced even in more resourced countries [20], widespread inclusion of children with disabilities in inclusive schools is not imminent and hence we need to contend with special schools for children with disabilities.

Schools for the blind and the student body in these schools have the following general characteristics[1]:

- There are about 32 schools for the blind in Karnataka, only 4 schools are run by the government. The rest are run by private non-profit organizations that get part of the support from government grants and the balance from donors.
- None of them collect any fees from the children and so education is free for the children.
- With a lone exception, no school offers science or math beyond middle school. After middle school, many children move to mainstream schools and pursue non-STEM subjects till high school and possibly beyond.
- There is a shortage of teachers who are trained in teaching children who are blind or low vision.
- More than 50% of the teachers in these schools are themselves blind and since they are also from the same school system, they have no formal education in science and math beyond middle school. This contributes to the vicious cycle of blind children not getting STEM education beyond middle school.
- Due to the shortage of teachers, a few grades are combined into a single classroom. In addition, due to the difference in ages at which students join the school, most grades have age-mixed students.
- Many of these schools are residential schools with most of the students being resident. These children are from semi-urban and rural areas, and hence stay at the school during

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[1] Given the paucity of data, it is hard to generalize across India. Our description is based on data and experience with schools in the state of Karnataka, where Bangalore is located.

the school year. Also, many children staying in hostels are orphans or come from low income families which cannot support them.

- There are very limited study materials available in the schools and these are strictly limited to the Braille version of the textbooks prescribed for the courses. The Braille books are copies of the mainstream texts with all figures, drawings, images, and tables left out. There are a few copies of the textbook per class and hence students have no study material after class hours.
- Since science is not taught beyond middle school, there are no science laboratories in these schools. Many schools have computer labs with standard desktop computers which are introduced to children after class 4. This is primarily to get the children to use computers through a screen reader to attain basic keyboard skills with some progressing towards minimal use of Word.

Students attending these schools are quite heterogeneous:

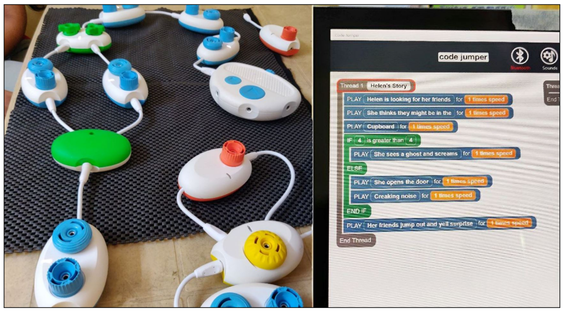
- Children come from very diverse cultural, socio-economic and language backgrounds. Children in the three schools we worked with, spoke a subset of English, Kannada, Tamil and Hindi. However, language of instruction in these schools is English.
- Coming from semi-urban or rural areas, parents of these children have very little access to information about resources for blind including availability of schooling. Because of which, parents start their schooling at age as late as ten.
- Majority of children stay in the school hostels during the academic term and do not have exposure to phones or other devices that their peers staying at home might have.

3 PROJECT TORINO

Torino is a physical programming environment developed at Microsoft Research Cambridge to teach computational thinking (following the UK curriculum) to children who are blind or low vision. The need for a physical programming environment and the related work are well detailed in [29]. Project Torino has been demonstrated to be effective in teaching CT to children in integrated school settings [29, 37]. Its success has resulted in Torino being released as a commercial product called CodeJumper [13]. We describe below the details of the hardware and software environment, the context of its development, and the results of its deployment, sufficient for understanding the differences and challenges in our study setting.

3.1 Overview of Project Torino and its Use in the UK schools

Figure 1 shows the hardware component of Project Torino along with a screenshot of the visual program corresponding to the physical program. It consists of different instruction beads and a hub which when physically connected, constitute computer programs that generate digital music or stories [29, 37]. The Hub controls multiple (up to four) threads of computational flow. Each thread of computation is made of a string of pods, each pod representing a statement of the program. There are pods for a single statement of the program, if-then-else, loop, merge (end-if) and pause/rest. The laptop has the interface to create visual programs for each thread and then for downloading the programs via Bluetooth to the Hub. Each thread of the program is then physically constructed by attaching the appropriate pods to one of the threads out of the Hub. After connecting the pods, the play button on the Hub causes the program to be executed. The result of the execution is that each statement in the pod results in an audio output. The output of all programs is audio (a clip of music, a line of spoken text, or a sound clip).



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Thread 1 Helen's Story
PLAY Helen is looking for her friends for 1 times speed
PLAY She thinks they might be in the for 1 times speed
PLAY Cupboard for 1 times speed
IF 4 is greater than 4
  PLAY She sees a ghost and screams for 1 times speed
ELSE
  PLAY She opens the door for 1 times speed
  PLAY Creaking noise for 1 times speed
END IF
PLAY Her friends jump out and yell surprise for 1 times speed
End Thread
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Figure 1: Torino hardware and software

Interesting and engaging outputs can be generated with multiple threads and multiple ways of parameterizing each pod's output. Each of the pods has one or two control knobs, which can be turned around physically to change the parameter of the attached pod. For instance, on the statement pods, one knob controls the speed of the sound output from that pod and the other knob allows for selection from eight alternate audio clips to be played out by that pod. The visual programs are constructed by the facilitators (who do not need to be professional programmers but can be easily trained to create programs on Torino).

A very important part of the Torino is its comprehensive set of curricular support material, including lesson plans, exercises and projects with graded progression from beginners to proficient users and support material for teachers, all in line with the UK School CT curriculum [4]. The goal is to ensure that children learn the CT concepts at the same pace and depth as their peers, regardless of their level of vision.

Since the study was conducted in integrated schools, the sessions were held with teams of two children with mixed visual abilities facilitated by a special educator.

3.2 Assessment

Morrison et.al [29] point out that the state of assessment of computational learning is at its infancy and that at present there are no scalable instrument in education literature for measuring computational learning [23]. Hence, they used teachers' reporting to evaluate the progress made by students on the assessment activities proposed by Brannon and Resnick [17] that includes the following:

Computational concepts: these include basic concepts like sequence, loops, conditions, variables, parallelism (threads), etc.

Computational practices: these include being incremental and iterative, testing and debugging, reusing and remixing, etc.

Computational perspectives: Expressing, connecting and questioning are the facets of perspectives.

The evidence for the children picking up skills along the three aspects of computational learning was gathered from the teachers' reports based on their open-ended diary entries and observations.

The motivation and engagement of students was measured using pre- and post-study questionnaires with a mix of Likert-scale and free response questions.

3.3 Choice of Torino for the Study

The need for a tangible or physical environment for computational learning by children who are blind or low vision has been well established. To meet our goal of introducing computational learning to children in schools for the blind in India, with the numerous challenges listed, we could start from the ground up and iteratively design a solution, with participation from teachers of computing and the children, suitable for children in schools for the blind in India. However, given that there is no curricular structure for Computational Thinking at this time in India, even in mainstream schools, such an approach, well executed by the Project Torino researchers, is infeasible at this time. Instead we chose to work with Project Torino for the following compelling reasons:

- The hardware of Project Torino has been designed extremely well and the project has been handed over for commercial production and distribution through American Publishing House, the largest provider of solutions for the blind around the English-speaking world. Thus, the benefits of volume production as well as continued upgrade and support may be available since we intend to deploy at scale.
- Project Torino has been demonstrated to be effective in enabling computational learning for children in the integrated UK school setting and the students in the study across multiple schools have demonstrated that they acquired skills comparable to their sighted peers.
- The study material and the reported experiences of teachers using Torino provide a starting point for our exploration.

Thus, in our view, we are left with a more tractable challenge of transplanting this solution to the schools for the blind in India. We explain our efforts and the findings in greater detail in the rest of the paper.

4 TORINO IN INDIA: PLAY AND PLAYFULNESS

Given the drastic diversity between the UK school environment and the schools for the blind in India, we chose to use the methodology called Ludic Design for Accessibility[36], that the authors have been developing over the past two years. The key aspect of the methodology is based on the articulation by Huizinga [22] that play and playfulness are central to being human so much so that the term Homo Ludens is more appropriate to define humans. The key design challenge is to ensure that while keeping the play intact, which in this case is an intended side effect, the acquisition of concepts in computational thinking is achieved.

The key implications of this approach in our specific project are, first, to introduce Torino as a toy for creative exploration of music, sounds and storytelling, rather than as a device for computational learning. Second, no comment was made either to the children or the teachers regarding computing or computational learning. We used the Music period or the Play period in the children's schedule to conduct the Torino play sessions. Third, each session began with a minimal structure and evolved in the direction the children wanted to take, with a very light touch by the facilitators. This required the facilitators to be prepared to introduce features of the Torino that were not planned for the session but the students stumbled into. Based on a debrief of a session, the content for the next session was modified. Essentially, every play session went through a unique path that was dynamically arrived at but managed outside the play session so that all the intended content was eventually introduced. The key principle was to keep the children and facilitators at play. Fourth, the evaluation of the learnings was done as part of the play rather than as a distinct 'testing' session. The facilitators engaged the children in banter about what was going on and through such conversations and observations of the proceedings, recorded the progress made by each child. These facilitators' notes were critical part of the assessment process as well as useful in planning the content for subsequent sessions.

5 STUDY DETAILS

The current study is the joint work between Microsoft Research India and Vision Empower Trust, a non-profit working with schools for the blind to improve science and math education at the primary school level.The three schools in which we conducted the study are part of the school network that the non-profit is already engaged with, and were thus inducted into this study. We obtained specific consent for our study from each of the school managements using a process approved by the Ethics board of Microsoft Research.

We obtained the consent from the schools for the participation of the children as well as to run the study at the school premises. The consent for the children who were resident at the school was given by the school in the capacity of in-loco parentis. For other children, the school obtained the consent from the parents using the details of the study and the details of informed consent provided by us.

The children were not compensated for the study. This was to ensure that the children (or their parents or teachers) do not influence the child to participate just for obtaining the material compensation. Since the children were to be engaged in play with songs and music during a regularly scheduled music class, the school also agreed with the above. The schools were not directly compensated for this study. Instead, the school management was in agreement that efforts to study the possibility of including computational learning at their school, if successful, will be the long term benefit for the school and the children.

5.1 Participants

Our study involved 12 children (10 boys, 2 girls), age 6-12 years, studying in grade 2, with visual abilities varying from partially sighted to complete blind. The children came from diverse cultural background and spoke multiple languages. These children were recruited casually from three different schools for the blind in Bangalore, India. Children were grouped together in pairs or triples based on common language of communication amongst teammates and with facilitator. There were three pairs, and two triples. None of the participants had any prior knowledge or experience using computers, nor any understanding of the core concepts that we tested over the duration of the study. Most of the participants lived away from their parents in school hostels. These schools start computer courses and labs from grade 5. Though none of our participants had ever used a computer/laptop/tablet, some of them had listened to songs and stories on YouTube while their parents operated smartphone for them as it was inaccessible.

The details of the participants and groups are presented in Table 1. The primary language of communication used by the children during the study is listed in the Language column followed by the native language in parenthesis, in cases where the primary language was English. The table also lists the number of sessions held for each group of children.

5.2 Facilitators of the Study

The role of the facilitator is to introduce the toy to the children with a pre-programmed story and then on to provide a light touch facilitation to the children during the play sessions: answering their questions(if any) and helping them to figure out details, if they asked for help. There were two facilitators in our study: First author (background in computing, no teaching experience) and Second author (background in Math and a few years of experience teaching college students). The role of the facilitators in the study was to design, plan and conduct play sessions, design guided play activities for children to learn, ask questions and engage in conversation with children while they play, and also to keep observation and video notes throughout the session. Neither of the facilitators had any prior training for teaching computational learning.

In every school, there was an assigned teacher identified by the school administration and their responsibility was to take care of and communicate with the facilitators about the children's comfort and discomfort during the play sessions. All play sessions took place in school premises during school hours.

6 PLAY SESSION SNAPSHOTS

The three schools had different spaces for conducting the study. In two schools, available non-classroom space was allocated for the sessions. In the third school, a large hall used for prayer was allocated. Torino sessions were held for the children during their music classes while the rest of their classmates continued in the regular classrooms. In all cases, the students and the facilitators sat on large dhurries[2] spread on the floor in two groups separated as much as the space allowed. Use of the floor was dictated by two factors: a Torino kit has a a large number of small parts and requires a large table to use so that the parts don't fall off. There were no such tables available in any of the schools, and hence all the play sessions were held on the floor. Second, we also wanted the children to have the freedom to run around and not be constrained to a chair and table. As it turned out, the floor provided for lot more degrees of freedom for the children as illustrated in Figure 2.

In the following section, we first provide a description of the experiences of the introduction and the first few sessions with the Torino. These highlight some of the pure play aspects of the study: children having the freedom to play or not to play, introduce new rules, negotiate with the facilitator or partners to try out something.

Figure 2: Children intensely at play

We find that children struggled and had frustrations with the devices as they didn't always work in ways expected, but also expressed joy at accidental discoveries that involved some stimulus such as sounds playing. In the Evaluation Section, we use the diary entries and observations to identify vignettes that convey the acquisition of the target skills during play.

We started our first session following the Use-Modify-Create approach [26]. Using this approach, we presented children with a pre-programmed story or song on Torino. Based on earlier conversations with the teachers, we created a Torino program that plays out a nursery rhyme well known to the children. The children were told that they were going to play with the toy that can play songs, make noises, and tell stories. Children were made to press play button by hand holding and were asked to listen to the output of the program. They were also familiarized, by guiding their hands, with the on/off switch, the volume dial, and the large play button on the hub. They were also led to explore the connecting wires and the pods. From there on, children were left to explore the toy with their partners.

6.1 Exploration

We found that the first function children start exploring is rotating the pods. Additionally, when first introduced with the toy, children connected random pods to the hub, connecting pods to different channels in the hub. We also found children switching the toy on/off frequently and pressing different buttons on the hub to see what they do. Figure 3 shows some snapshots of children at play.

Enthused about discovering something that made a range of funny sounds and music, children were usually very impatient in the beginning, as they aimed to explore every feature of the toy. We found that upon finding some new feature, the children took their partners' hands and carried them to the toy's newfound pod/feature and showed how it worked. Since the children were classmates, they were comfortable around each other. First play sessions usually ended with children sequentially connecting all the Torino pods and playing the program. Children were usually familiar with basic functions of the hub and the play pods by the end of the second play session. They also divided the pods based on whether they make any sound. So, pause, loop, if-else pods were

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[2] A dhurrie is a thin flat-woven rug or carpet used traditionally in South Asia as floor-coverings.

Group	Name	Age	Extent of vision	Language for Interaction	No. of sessions
1	S1A1	6	Blind	English (Kannada)	11
	S1A2	12	Blind	English (Odiya)	11
2	S1B1	7	Partially sighted	English (Kannada)	11
	S1B2	7	Partially sighted	English (Kannada, Marathi)	11
3	S2C1	6	Blind	Kannada	7
	S2C2	7	Partially sighted	Kannada	7
4	S2D1	7	Partially sighted	Kannada	8
	S2D2	7	Partially sighted	Kannada	8
	S2D3	8	Partially sighted	Kannada	8
5	S3E1	7	Partially sighted	English (Kannada)	7
	S3E2	7	Partially sighted	English (Kannada)	7
	S3E3	7	Blind	English (Hindi)	7

Table 1: Summary about study participants

Figure 3: Children 'training' with Torino during play session in school.

non-sound pods while the only sound pods were the play pods. Children were usually uninterested in non-sound pods.

Initially, as they manipulated the pod connections, children seemed to be confused about where the sound was coming from. Some participants, with little or no vision, would bring their ears close to the hub to find where the sound originated from. Upon discovering the speaker in the hub (In Torino kit, the speaker is located in the Hub and none of the other pods have speakers. They only logically contribute to a particular sound clip but physically the Hub outputs the sound), most of participants would lean their head towards the hub when running their program to listen to the program better. In some instances, this would create a conflict between participants in the same team as they wanted to hear close to the hub.

Once the children were aware of the various functionalities of the toy, they started to ask why play pods do not make sound like the hub. Sometimes, they also involved facilitators in their conversation and asked questions to know more about the features. In one such scenario, when children discovered about a computer's requirement to run the toy, they asked the facilitators questions on how the toy is connected to the laptop and if they could run the programs directly from the computer.

Children did not seem to be interested to trace the program physically because they would rather do this mentally. However, over the period, with consistent efforts from the facilitators, they learned to trace the program when run. Some children would start tracing first line of their program from the hub due to which they would be left with an extra pod in the end which did not make any sound. Confused, they would check connections and values on pods and run the program again. At this point, facilitator would get involved to teach the correct start point of the program i.e. from the first pod connected to the hub.

Help-seeking typically happened at apparent dead-ends. For instance, when one child pulled a wire and the Hub began making noise, after unsuccessfully attempting a few items, the pair turned to the facilitator for help. Minimal support, guiding their hands to demonstrate how a pod has come unplugged from the Hub and how to put it back, was provided and the exploration continued. Over a few play sessions, children discovered this way, features such as stop button on hub, multiple channels on hub, a laptop's requirement to run programs on the toy, wires on play pods and how they are connected, and discovering various pods that do not make sound.

Occasionally, one member of the team would monopolize time with the Hub and the other would complain to the facilitator. The facilitators would then introduce some way of negotiating the shared use, either by asking them to take turns with the Start button, or by proposing that one controls the Hub, while the other switches a knob. But most of the time, children worked out some arrangement to share the time with Torino.

Children became experts in assembling and disassembling the toy kit. They would open the kit by themselves, find hub, pods, switch on the hub and connect the play pod and would wait for the facilitator to start the laptop (Torino software). At the end of the session, they would disconnect everything, make sure the hub is switched off and keep it all back in the box and close it and give it to the facilitator. This helped children in spending more time with the toy, manipulate more connections and thus, more chances of learning new things.

The children found it easy to connect the pods. Those with more vision brought their heads close to the pods to locate the connectors, while others with less vision used one hand and a finger to locate the jack slowly, using it as a reference for plugging in the wires. Children would recognize the click sound coming after each successful connection.

Children demanded to have their own stories and songs on Torino, asked if they could record songs in their own voice and play on the toy, and if they could play stories in their native language instead of English. In subsequent classes, we recorded the children's favorite songs in their own language or favorite noises, and that enabled them to create new stories.

7 EVALUATION

As pointed out by Morrison et. al [29], assessing computational thinking is in its infancy and, thus, we follow the same evaluation process as in the UK study, based on observations and reporting of the facilitators. We did not have any accepted standard tests to evaluate the concepts learned and further, even if available, the scale of the pilot study precluded the use of those tests. Our goal was partially to replicate the typical evaluation in a blind school with limited resources - where evaluations are conversations rather than fixed tests. Our goal was not to separate the play from the assessment, rather to combine the two seamlessly. The strategy used was the following: the facilitator suggests an activity (make a song or tell a story with Torino) for the children and while they are doing it, engage them in casual banter about what is going on. However, we had pre-created a set of facets to be interrogated and the expected responses, which would suggest the understanding of a concept, that are broadly the same for every child. We organize the following into sections, one for each of the key computational learnings listed in the Research Question. And in each section, anecdotes from the facilitators' diary or from the video or remembered observation is presented to convey the flow of the evaluation and to support the claim that the concepts were in fact understood by the children.

7.1 Computational Concepts: Sequence

Sequence is a key concept in programming which says that a particular activity or task can be expressed as a series of individual steps or instructions that can be executed by the computer. In Torino, the series of tasks become a series of tangible pod connections which finally construct the programs. To check the sequence of their program, each child was taught individually how to physically trace a program running on Torino. Programs on Torino start from the hub, thus making the very first pod connected to the hub representing the first line of code in the program. Children were taught about the start point (the hub) and the end point (last pod connected in the pod thread) of a program on Torino. Below is described an observation where a participant learned about sequences while trying to play animal voices on Torino:

"During his first session, S1B1 disconnects two play pods from the hub and connects them together end to end. He starts to turn play pod knobs expecting similar audio output like when play pods were connected to the hub. He quickly finds the hub channel for animal voices, plugs one play pod back to it and starts turning its knob. The hub plays sheep's voice when play pod knob is turned. S1B1 takes another play pod, connects it to the thread, and sets its audio to horse's voice. He presses the play button and starts following the play pods as sheep's voice is played followed by horse's voice. In next five minutes, he adds more play pods to the thread, sets them for different animal voices, presses play button and follows the pods along with the program."

To evaluate if children understood the step by step building and execution of programs, they were asked to build a poem of their choice in its correct sequence. While they were building it, the facilitator asked them to also explain what they were doing and planning to achieve at each step. After successful completion of first part of evaluation, the facilitator deliberately added a bug to the program either by changing the sequence of pods or by changing the values of sound knobs on play pods. The second part involved children debugging the program to get the output in correct sequence.

7.2 Computational Concepts: Threads

Threads in programming are basically sequences of instructions happening in parallel. In Torino, threads are represented in the form of channels which allow maximum four programs to be executed simultaneously. While exploring different features and functions of Torino, children discovered multiple channels on the hub. They soon connected a bunch of play pods in all the channels and hit the play button only to listen to chaotic but funny musical combinations. Children often played a story in one thread and background music/sounds in another thread. However, some children faced difficulties while syncing two or more threads of the programs. In the following instance, the pause pod was introduced to children when they faced difficulty syncing the bird voices with their story.

"S2D3 is building a story program on Torino to which S2D1 wants to add bird sounds as background music. He asks the facilitator to put bird songs in one of the hub channels and connects a play pod to it. The hub runs two parallel programs: story and bird sounds. When the programs run, they overlap and that is not what he wants. S2D1 asks the facilitators how to make the bird sounds come "late"."

Pause pod was introduced to resolve the above problem and simultaneously introduce a facility of variable pause periods that the pause pod provides.

Confusion between threads did come up when programs of two threads were in sync. In that scenario, facilitators would ask the children to remove one thread connection and play the other to be able to distinguish better between output of two threads. To evaluate the concept of threads with children, facilitators asked children to add and sync background music/sound with a poem created on Torino by the facilitators. While building their program, children were asked to think aloud how they are approaching each step, what pods they are going to use, etc. While they programmed, facilitators asked questions on different steps of programming two threads. Often, a bug was created by the facilitator in the program to test children's understanding of how threads work on Torino.

7.3 Computational Concepts: Loops

After the play pod, loop pod was the most frequently used pod during play sessions. In Torino, the loop pod has only one control knob on it, which decides the number of times program will go in a loop, the maximum number being 8. While introducing loop, children were given insufficient number of play pods and asked to build a program. The loop gave them the benefit of less hassle of connecting too many play pods and this pushed children to practice loops more. Most of the children instinctively started to use loop pod whenever there was any repeated audio in their program. However, some children struggled with the direction of flow of program when connected to a loop pod, as demonstrated in an observation below:

"S1A2 faced some difficulties while tracing programs with loops. She would get confused and wait for the repetition to end and next play pod to speak. To address this, the facilitator took her hand and kept it going in circle touching connections in the loop for as many times as the value on the loop pod. Similarly, S1A2's Torino partner S1A1 had difficulty finding the correct direction of sequence in the loop."

7.4 Computational Concepts: If-Else

Conditional statement, If-Else was one of the computational concepts introduced later to the children. The physical design of If-Else Torino pod is distinct from all other pods. It has one wire for connection to the previous pod in the sequence and two channels, if channel and else channel. Each channel is accompanied by a knob value which decides the direction of flow of program. When number set on If-knob is strictly greater than the number set on Else-knob, If command is run otherwise Else command is run. Physical distinction due to the design of the knobs made it easier for children to differentiate between If-knob and Else-knob. The concept of conditionals was presented to children as a solution to their constant competition with each other to play their own songs on Torino.

Following is the description of one such instance:

"A group of three children was trying to make stories with some funny human voices in Torino. S2D3 and S2D2 agreed to a common story ending but S2D1 wanted a different ending. To resolve this issue, facilitator used the If-Else pod and asked them to build their programs on the two channels of If-Else pod. Then the value of knobs were randomly changed on the If-Else pod and children were asked to set values in a way so that their program played and not the other's."

7.5 Computational Practice: Tracing and Debugging

Some of the participants learned how to trace programs by the end of first session but later faced difficulties while tracing programs in a loop.

"While tracing his programs physically, S2C1 would stop at the loop pod until the program came out of the loop. After the program came out of loop pod, he moved ahead along with the program without seeming to face any other issue. Upon being asked why he did not follow the program in loop, he confessed being unaware of the correct direction of flow of the program in loop. Over next few sessions, facilitators taught S2C1 to go with the first pod he connected to the loop pod."

An interesting motivation for tracing programs was seen among children when they realized that tracing their programs helped them in saving time during debugging. Many children would try to avoid bugs in their program by building them carefully and following each output. Debugging requires collective knowledge of multiple computational concepts used in programming.

"S1B1 wants to play "YeeHaw" on Torino. He builds a loop program with single play pod on loop. He turns the speed knob to know the audio set on sound knob. The hub speaks, "YeeHaw". He picks up the loop pod and sets the number of loops to six and presses the play button. The hub makes a funny burp sound which denotes error in program. To confirm, S1B1 pushes the play button again, to which the hub makes another burp sound. Prashant quickly checks the play pod connections with loop and finds a wrong wire connection. He connects the wire to right jack and presses the play button. The hub says "YeeHaw" for six times."

7.6 Computational Perspectives: Expressing and Connecting

Computational perspectives focus on the spirit of creating with others and creating for others. Children were taught to think aloud while building their programs. This not only helped their teammates be updated with changes to the program, but also helped the facilitators in understanding and analyzing the gap in learning when children built program which gave output different than what they expected. Before every program, it was a ritual to share with the team what program you are creating and what pods would be needed to execute this program. Evaluation for computational perspectives were totally observational and based on children's general behavior and attitude during play sessions. Following are some instances when children demonstrated this skill:

"S1B1 asks S1B2 to repeat a particular animal sound using loop pod. S1B2 spends some time figuring out where to add the loop pod. Knowing this, S1B1 takes S1B2's hand and shows her the pod connections where she should add it."

"S2C2 got his turn to play a song on Torino but he was struggling with setting the sound knob to an audio. He was turning the knob frantically while the knobs needed to be turned slowly to set an audio. S2C1 took S2C2's hand and showed him how to slowly turn the knob. In next session, facilitator noticed S2C2 setting audio on play pods by turning the knobs slowly."

Sometimes, the groups were combined and everyone had to make a program that they wanted to present to the group. Children helped each other in building interesting stories and debugging buggy programs.

7.7 Questioning

Enabling children to ask more questions was an important aspect of our teaching methodology.

"During one session, S1A1 found a very long wire in the box. He took the wire and connected one end to the hub and one end to the play pod and pressed the play button to check if this setting worked. It worked and from then on, he and his teammate used the long wire to connect hub to the first pod in the program. This facilitated in getting better placement for pods due to extra space now, and this also helped in easier manipulation of pods compared to earlier."

"S3E1 connects pause pod to the hub and presses the play button and hears "half a beat". He rotates the speed dial on the pause and expects sounds but gets disappointed soon when hears audio: "one beat", "quarter beat". He finds more pause pods from the box and connects to the hub and begins to rotate the speed dials. After trying everything, he complains to the facilitator that the pod is not making any sound and what is the use of such pod in Torino".

7.8 Enjoyment and Engagement during Play sessions

Children enjoyed playing and building programs on Torino and sharing it with their teammates. They would often have conversation with the facilitators on where to purchase the toy from, if they could attend play sessions more frequently, etc. One child deliberately did not inform the facilitator about the lunch bell and skipped his lunch period in order to spend more time playing Torino. Children always wanted new stories and fresh content to be played on Torino. Children enjoyed playing with funny sounds on Torino.

"S1A1, the youngest participant of our study, loved to play "YeeHaw" on Torino. He would also say "YeeHaw" for "yes". Other children would also shout Yeehaw with him and laugh out loud."

7.9 Summary of the Evaluation

The evaluation process was done through play such that the children were unaware that they were being 'tested'. However, the facilitators kept systematic notes about the progress, the questions asked, and the answers given by each child. After each session, analysis of these resulted in fine tuning and better replication with the next group. The following summarizes our conclusions about the answers to our Research question: did the children acquire computational concepts?

As indicated in the Table 1, the number of sessions for the groups varied from 11 to 7.

- Flow of control: This includes knowledge of sequences and threads and this was attained by every child in our study who demonstrated their knowledge by repeatedly using them to construct stories or songs.
- Loops and variables: This concept included identification of the sequence of statements that are involved in the loop took varying times for the groups but eventually every child became competent in its use. Later, it became the favorite construct for many children.
- If-Else: At first, all the groups had trouble grasping this concept but all children had mastered this concept by the end of the study.

Over multiple sessions and in playing with different songs, music and stories, all children made progress with computational practices of tracing and debugging as well as in working with others, explaining their reasons for their actions and by helping each other in fixing bugs and learning new features. However, we did not do any evaluation of each child's competencies in these more abstract aspects of computational learning.

8 DISCUSSION

Our experience with the project over the past year reinforces that creative, playful and persistent iteration of ideas can lead to addressing many of the challenges listed here over time. In many ways, the children co-created the play sessions and the methodology over multiple play sessions by including the facilitators as one of the players. It should be noted that the facilitators themselves were involved and interested in the play because each session had unexpected and informative learning for them, led by the progress made by children and by engaging with what they wanted to do with the toy.

Given that we were not constrained by a set curriculum or the need to conform with some set standard, we had considerable leeway in going with the flow of the sessions. Each session began with certain assumptions made about what aspects would be conveyed in that session but will take entirely different directions based on the children's learnings: for instance, when a child first figures out how to connect a pod to another, the next ten minutes would be spent connecting each available pod in a long row (as seen in Figure 3) and pressing the play button frequently, without being concerned about what is being played out, and stopping when all the pods are exhausted. The fiddling with knobs in some pod and listening to the sounds. This will be considered chaos in any regular classroom setting with an assigned instructor and a lesson plan.

The approach of largely unstructured play was something we questioned as a team, at least at early stages, and we learnt as we went along. For instance, during our early sessions, we noticed at least one group struggling with the devices - often frantically doing things with the devices without any obvious intent. At such points, it was tempting to turn to more instruction and structure. However, by the third session, the same child was observed methodically connecting the pods to arrive at a simple song that was played end to end. Similar instances early on led the facilitators in subsequent sessions with other children to trust the methodology and to go with the flow and to see that each child arrived at different learnings through different means.

It was also clear to us after the first session that it was futile to attempt to keep the lesson plans for every session or to attempt to ensure every child reached certain milestones in synchrony. Even at the 7th session, some children were not be able to identify a specific pod, but she may be adept at connecting pods and in debugging. As a team they still made progress and transferred the learnings to each other implicitly rather than by any set process. Thus, the detailed lesson plans in the Torino Teachers guide were of little use to us. In the structured plan, simpler pods are introduced first and as children become comfortable using them, additional pods are introduced in sequence so as to 'not overload' the children.

We found that opening up the whole kit for the children was the most effective way to contain their curiosity since otherwise they were more interested in what is left in the box rather than exploring what is in their hands. This also allowed for serendipitous discovery of features: a child discovered an extension cable in the kit which is an incidental add-on, and used it to ensure that the Hub remained in his hands (for him to listen to the audio that emanates only from the Hub) while handing over the play pods to the team mate.

For another example, the desire to have their own stories in their own language was expressed very early in the project, and we responded by finding out the children's favorite stories and music and creating the audio files needed to create diverse programs. Another example is the use of a computational concept in resolving the conflicting choices made by children within a group: the If-Else pod was used to allow two separate endings of a story to be placed into the program with children taking turns playing either version.

We continuously adapted our approach to the conduct of the play sessions. The use-modify-create approach [26] disintegrated in the first session to use-destroy-demand-something-else approach, with children demanding their favorite songs and stories to be told. With the ownership of the content established, the subsequent sessions were a lot less chaotic and more productive. Thus, one of our goals is to create a guidebook of plausible rules for the games that the children can play, including guidance about how the rules can be dynamically changed. A key insight for facilitators will be to be prepared for multiple, often unexpected, ways in which each child will explore the toy, given the freedom to explore. And the facilitators should be willing to work with uncertainty of how time in each session will be utilized.

Another learning from this study is the importance of using well manufactured artifacts like Torino in such novel situations. The Torino kit itself may or may not be the right candidate for deployment at scale for computational learning in India but establishing that was not the primary goal of this study. Instead the focus of this study is the methodology to be used in such settings. However, to arrive at any conclusion from such a study, it is necessary that the tools used are rugged and functional. None of the devices broke, despite fairly rough handling, which is an important part of making for useful learning tools. As past research has shown, if children or teachers sense a learning tool is fragile, they are a lot less likely to use it.

8.1 Limitations of the Study

There are several limitations in our study.

1. The sessions were conducted by non-expert individuals (from the point of experience in teaching computational learning), who were both part of the project team and hence committed to the success of the study. For this approach to scale. We need to train the teachers at the schools for the blind to take up the role of facilitators and this is a part of our immediate next step.
2. The sessions were conducted in periods allotted for games or music. Even though our study included 'play' and music, it did take children away from the outdoor play or interactions with a larger group of children during the games/music period. Even though children possibly enjoyed these sessions more because it was a welcome change from their normal routine, it remains to be seen if similar level of enjoyment and engagement is maintained if this activity becomes a normal scheduled period.
3. The sessions were conducted with the same small set of students from each of the schools while their classmates were engaged in their standard activities. In a scaled setting, a class of may be 10 to 12 students (the average class size in the grades in the schools we worked with) may need to be simultaneously engaged with the Project Torino. This will require 3-4 sets of Torino kits and matching number of laptops/tablets. More importantly, we need a facilitator who can set up all these groups of students and keep them engaged for the duration of a period, usually about 45 minutes. Based on our experience, this is going to be a major challenge. We do not have any solutions for how this may be addressed. We believe that the PC interface needs to be much more simplified among other things, but we are yet to explore this question in detail.
4. By using play as a medium and introducing computational learning as we have done, computational concepts have been demonstrably absorbed. However, it is not clear if the children will be able to reuse this learning in the context of computational learning in the standard vocabulary.

9 CONCLUSION AND FUTURE RESEARCH

We have demonstrated the potential of using a play-based approach to introduce computational learning with Torino in schools for the blind in India. The value of play in children's healthy physical and mental development has been well established. Further, extensive research has been done to illustrate the benefits of play as a powerful medium for learning across ages. Given the many constraints and challenges faced by children who are blind or low vision in low resource settings, we suggest that the play-based low-touch high-flexibility approach described here, though we have demonstrated grasp of only a small set of computing concepts, is a powerful way to introduce computational learning in the target environment.

Our ongoing research is in two major directions. First, to continue further studies to evaluate, without breaking the fourth wall of play, the retention of concepts learnt over an extended period of time and if the children are able to graduate to the next levels of competence in computational learning. Second, to study if we can transfer the play-based method to teachers of children who are blind so that this approach can be scaled to a large number of schools for the blind in low-resource environments around the world.

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