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

Leave Authors Anonymous
for Submission
City, Country
e-mail address

Leave Authors Anonymous
for Submission
City, Country
e-mail address

Leave Authors Anonymous
for Submission
City, Country
e-mail address

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.

Author Keywords

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

CCS Concepts

•**Human-centered computing → User studies; HCI theory, concepts and models; Accessibility design and evaluation methods;** Please use the 2012 Classifiers and see this link to embed them in the text: `https://dl.acm.org/ccs/ccs_flat.cfm`

INTRODUCTION

Learning computing could be transformative for people who are blind or low vision, just as 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, 26, 29]. A foundational requirement for this is introducing children to Computational Thinking (CT) [21] at an early age. Many countries, including the UK, have made computing a part of the regular curriculum starting at the primary grades [9, 8, 11, 33, 16] and there are corresponding efforts to introduce CT skills to children who are blind or low vision [34, 18, 15].

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 [20, 31]. 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 for blind and due to which, children from multiple grades are often combined into a single 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.

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 education. A curriculum for CT has been recently created under the aegis of ACM India [10], however it is for sighted children. 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, and be in a position to consider STEM learning or careers for the future. 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.

CHI'20, April 25–30, 2020, Honolulu, HI, USA

ISBN 978-1-4503-6708-0/20/04. . . $15.00

DOI: `https://doi.org/10.1145/3313831.XXXXXXX`

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]. 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 [23, 40, 35, 27]. We zeroed in on Torino Learning Environment (Torino) ([30], [36]), 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 [37], 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 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 set out to answer the following research question.

Research Question Our basic research question was around whether the Torino model can be replicated in a low-resource setting with limited structured teaching, and reliance on play instead, to build competence in computational thinking concepts. Specifically, can we examine that the children pick up the following skills[4]:

1. Computational concepts: sequence, thread, loop and if-then-else,
2. Computational practice: tracing and debugging
3. Computational perspectives: expressing and connecting

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'[6, 1] 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 [39]. There is also to a Right to Education law[38] 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 organizations working in the area estimate that less than 50% actually attend school. Of 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 [22], 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 and the rest started and 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 the school year. Also, many children staying in hostels are orphans or come from low income families which cannot to support them.
- There are very limited study material 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.

---

[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.

- 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 non-homogeneous:

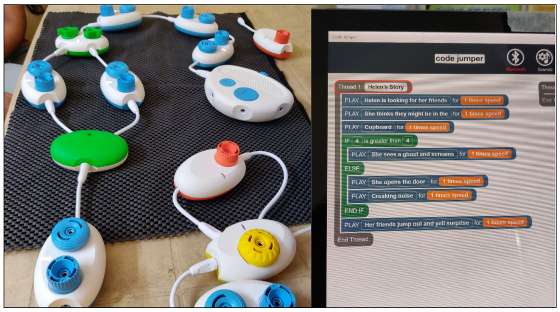
- Children come from very diverse cultural, socio-economic and language backgrounds. Children in the three schools we worked with, spoke a sub set of English, Kannada, Tamil and Hindi. However, language of instruction in these schools is English.
- Coming from semi-urban or rural areas, parents of these 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.

PROJECT TORINO

Torino is a physical programming environment developed at Microsoft Research Cambridge to teach computational thinking (following 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 [30]. Project Torino has been demonstrated to be effective in teaching CT to children in integrated school settings [36, 30]. 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.

Overview of project Torino and its use in the UK schools

Figure 1 shows the hardware component of Project Torino along with a screen shot 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 [36, 30]. 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 results 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).



```
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
```

Figure 1. Torino hardware and software

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

A very important part of the Torino is the 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 Computational Thinking curriculum [4]. The goal is to ensure that children learn the CT concepts at the same rate and depth as their peers, irrespective of their level of vision.

Assessment

Morrison et.al [30] 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 [25]. Hence they used teacher reporting for assessing the progress made by the students on the assessment activities proposed by Brannon and Resnick [17] that includes the following:

1. Computational concepts: these include basic concepts like sequence, loops, conditions, variables, parallelism (threads) etc.
2. Computational practices: these include being incremental and iterative, testing and debugging, reusing and remixing etc.
3. 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.

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 the 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 integrated UK school setting and the students in the study across multiple schools has demonstrated that the children acquired skills comparable to their sighted peers.

- The study material and reported experiences of teachers using the Torino provide a starting point for our exploration.

Thus, we are left with a more tractable challenge (in our view) of transplanting this solution to the schools for the blind in India. in the rest of the paper we describe our efforts and the results in detail.

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[19], that the authors have been developing over the past two years. The key aspect of the methodology is based on the articulation by Huizinga [24] 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 implication of this approach in our specific project is to introduce Torino as a toy for creative exploration of music, sounds and storytelling, rather than as a device for computational learning. Second, no mention was made about computing or computational learning either to the children or to the teachers. We used the Music period or the Play period in the children's schedule to conduct the Torino sessions. Third, every session was started with a minimal structure and evolved in the direction the children wanted to take with a very light touch by the facilitators. Based on the learnings from one session the content for the next session was sketched to bring in the concepts that need to be introduced, but not strictly adhered to. The focus at all times was to keep the children and the 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 happening and through such conversations and observations of the proceedings recorded the progress made by each child. These were used as inputs to outline the content for the subsequent sessions.

STUDY DETAILS

The current study is the joint work between a research institution and a non-profit working with schools for the blind to improve science and math education at the primary school level. The three schools that we conducted the study are part of the school network that the non-profit is already engaged with and hence were 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 the research institution.

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 in 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.

Participants

Our study involved 12 children (10 boys, 2 girls), age 6-12 years, studying in grade 2, with visual abilities varying from complete blind to partially sighted. 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, if the primary language is English. The table also lists the number of sessions held for each group of children.

Facilitators of the Study

The role of the facilitator was to facilitate the play session while children engaged in to making complex programs in a playful learning environment at their school. 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, designed 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 during 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 comfort and discomfort of children during play sessions. All play sessions took place during school hours in school premises.

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 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 large number of parts and needs a large surface for spreading out and using without them falling on the floor and becoming inaccessible to the children and these schools had no such lab tables. 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 a lot more degrees of freedom for the children as illustrated in Figure 2

Figure 2. Children intensely at play

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, introduce new rules, negotiate with the facilitator or the partner to try out something, 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 Section **??**, we then use the diary entries and observations to group vignettes that convey the acquisition of the target skills by the children through such play.

During first play session which is mostly introductory, facilitators and children are matched based on common languages spoken followed by a brief description of play sessions and Torino as a music toy. We started our sessions broadly following the "Use-Modify-Create" approach [28]

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 and 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.

Exploration

We find that the first function children start exploring is rotating the pods. In addition, on being introduced with the toy for the first time, children connect random pods with 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 to find something that makes variety of funny sounds and music, children are usually very impatient in the beginning as they aim to explore every feature of the toy. We found that upon finding any new feature, children took hands of their partners and bring them to the new found pod/feature of the toy and showed how that worked. Since children were classmates, they were comfortable around each other. First play session usually ends with children connecting all Torino pods in sequence and playing the program. By the end of second play session, children are generally fluent with basic functions of hub and play pods. They also divide pods based on if they make any sound. So, pause, loop, if-else pods are non-sound pods while play pods are the only sound pods. Children were usually uninterested in non-sound pods.

Initially, children seemed to be confused about where the sound is coming from when they manipulate the pods or connections. Some children with little or no visibility bring their ears close to the hub to find where the sound is coming from. Upon discovering the speaker in the hub (In the Torino kit, there is a speaker only in the Hub and none of the other pods

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 in school during play session.

have speakers. They only logically contribute to a particular sound clip but physically the Hub outputs the sound), most of participants lean their head towards the hub when running their program to listen to the program better. In some instances, this would create an issue between participants in same team because even they want to hear close to the hub.

Once children are aware of various functionalities of the toy, they start to ask why the play pods do not make the sound and only the hub does. They soon discover that a computer is required to be switched on to play the songs on Torino. They would ask the facilitators 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 of time 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 get involved to teach the right 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, after one child pulled a wire and the Hub stopped making any noise and trying a few things unsuccessfully, a pair turned to the facilitator for help. Minimal help, guiding their hands to show how a pod has come unplugged from the Hub and how to put it back, was given and the exploration continued. Over few play sessions, children discovered in this way, features such as stop button on hub, multiple channels on hub, requirement of a laptop to run programs on the toy, wires on play pods and how they are connected and finding different pods which do not make sound.

Sometimes, participants also involved facilitators in their conversation and ask questions to know more about features. In one instance, children found out about the requirement of a laptop to run the toy. They asked questions on how the toy is connected to the laptop and if they can directly use the laptop to play their programs.

Occasionally one member of the team will monopolize time with the Hub and the other will complain to the facilitator. The facilitators will then some way of negotiating shared use, asking them to take turns with the Start button or by suggesting that one controls the Hub and the other make changes to some knob. But most of the time the 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 enabled them to create new stories.

EVALUATION

In this section, we describe in detail our approach to evaluating children for computational concepts, practices and perspectives. 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 to have no separation between the play and the evaluation and to seamlessly mix the two. 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 1. 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.

Computational Concept: 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 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 and 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 voice's, presses play button and follows the pods along with program."

To evaluate if children understood step by step building and execution of programs, they were asked to build a poem of their choice in its correct sequence. While they are building it, the facilitator also asked to explain what they are doing at each step 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 sequence of pods or by changing values of sound knobs play pods. The second part involves children debugging the program to get the output in correct sequence.

Computational Concepts: Threads

Threads in programming are basically sequences of instructions happening at the same time. 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 channels and hit the play button only to listen to chaotic but funny musical combinations. Children often played story in one thread and background music/sounds in another thread. However, some children faced difficulties while syncing two or more threads of programs. In following instance, pause pod was introduced to children when they faced difficulty syncing bird voice 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. Karthik asks the facilitators how to make the bird sounds come "late"."

Pause pod was introduced to resolve the above question 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 facilitator. 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 facilitator in the program to test children's understanding of how thread works on Torino.

Computational Concepts: Loops

After 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, maximum number being 8. While introducing loop, children were asked to build a program while play pods available to them were less than required. The loop gave them the benefit of less hassle of connecting too many play pods and this pushed children to practise 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 direction of flow of program when connected to loop pod, as demonstrated in an observation below:

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

Computational Concepts: If-Else

Conditional statement, If-Else was one of 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 of 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 or else, else command is run. Physical distinction due to design of 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 making stories with funny human voices in Torino. S2D3 and S2D2 agreed to same story ending but S2D1 wanted to play another ending. To resolve this issue, the facilitator used the if-else pod and asked them to build their programs in 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 that their program played and not the other's."

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 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 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."

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 team mate 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 programming. 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 S1B1'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 need 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 want to present to the group. Children helped each other in building interesting stories and debugging buggy programs.

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"

Enjoyment and Engagement during Play sessions

Children enjoyed playing and building programs on Torino and sharing it with their group mates. They would often have conversation with 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."

Summary of the Evaluation

The evaluation process was done through play such that the children were unaware that they were being âĂŹtestedâĂŹ. However, the facilitators kept systematic notes about the progress, the questions asked, and the answers given for every 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 (at the time of writing) and some groups have sessions scheduled in the following weeks.

- 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 including the 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. It became the favorite construct of many children towards later play sessions.

- if-then-else; All the groups had difficulty understanding this but as of this writing all children except those in Group 5 have acquired this concept.

Over multiple sessions and in playing with different songs, music and stories, all children made progress with computational practice 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.

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 must be noted that the facilitators were engaged in play during and were themselves immersed in the play since every session had surprising and insightful learnings for them, led by the progress made by the children and by working with what they wanted to do with the toy.

Given that we were not constrained by a set curriculum or the need to confirm with some set standard, we had considerable leeway in going with the flow of the sessions. Each session would start with certain assumptions made about what aspects will be conveyed in that session, but would take entirely different directions based on the leanings of the children: for instance when a child first figures out how to connect a pod to another, the next ten minutes will be spent in connecting every 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 stop when the pods are all 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 frenetically 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 to methodically connect 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 Teacher 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 a) contain their curiosity, else they were more interested in what is left in the box rather than exploring what is in their hands and be 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 a the play pods to the team mate [2]

As another example, the need to have their own stories in their own language was articulated very early in the project and we responded by finding out the children's favorites and creating all 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 both ending of a story be put into the program with children taking turns in playing either version.

We also adapted own approach in the management of the play sessions. The use-modify-create approach [7] disintegrated in the first session to use-destroy-demand-something-else approach, with the children demanding to have their favorite songs are stories 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 guide book of plausible rules for the games that the children can play, including guidance about how the rules can be dynamically changed.

Another learning from this study is the importance of using well manufactured artifacts like the Torino in such novel situations. The Torino kit itself may or may not be 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 conclusions 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.

Limitations of our work

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 non-trivial task.

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 of 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. Using play as a medium and introducing computational learning as we have done has resulted in demonstrable absorption of computational concepts. 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.

CONCLUSION AND FUTURE RESEARCH

We have demonstrated the potential of using a play based approach to introducing computational learning with Torino in schools for the blind in India. The importance of play in the healthy physical and mental development of children has been well established. Further there has been considerable work in highlighting 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, continue further studies to evaluate, still 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 the large number of schools for the blind in low-resource environments around the world.

REFERENCES

[1] Census Digital Library Govt. of India. `http://censusindia.gov.in/DigitalLibrary/Archive_home.aspx`. (????).

[2] Convention on the Rights of Persons with Disabilities (CRPD). `https://www.un.org/development/desa/disabilities/convention-on-the-rights-of-persons-with-disabilities.html`. (????).

---

[2] A supplemental video shows this among other activities in a typical session

[3] IBEF-Report: Science And Technology in India. https://www.ibef.org/archives/detail/b3ZlcnZpZXcmMzQ1NzQmMTEz. (????).

[4] National curriculum in England: Computing Programmes of Study. https://www.gov.uk/government/publications/national-curriculum-in-england-computing-programmes-of-study/national-curriculum-in-england-computing-programmes-of-study. (????).

[5] Scratch. (????). https://scratch.mit.edu/

[6] 2011. Census of Government of India 2011. http://censusindia.gov.in/2011-Common/CensusData2011.html. (2011).

[7] 2014. World Health Organization. Universal Eye Health: A Global Action Plan 2014-19. https://www.who.int/blindness/AP2014_19_English.pdf. (2014).

[8] 2015. Computing Our Future. Computer programming and coding: Priorities, school curricula and initiatives across Europe. http://fcl.eun.org/documents/10180/14689/Computing+our+future_final.pdf/746e36b1-e1a6-4bf1-8105-ea27c0d2bbe0. (2015).

[9] 2016. Computer programming seen as key to JapanâĂŹs place in âĂŸfourth industrial revolution. Japan Times. https://bit.ly/2JnLwrJ. (2016).

[10] 2017. CSpathshala. Curriculum. https://cspathshala.org/. (2017).

[11] 2018. EuropeanSchoolnet launches its first study visit on Computational Thinking in Norway and Sweden. EuropeanSchoolnet. http://www.eun.org/news/detail?articleId=1845581. (2018).

[12] 2019. Alice. (2019). https://www.alice.org/

[13] 2019. CodeJumper. https://codejumper.com/. (2019).

[14] Jeffrey P. Bigham, Maxwell B. Aller, Jeremy T. Brudvik, Jessica O. Leung, Lindsay A. Yazzolino, and Richard E. Ladner. 2008. Inspiring Blind High School Students to Pursue Computer Science with Instant Messaging Chatbots. In *Proceedings of the 39th SIGCSE Technical Symposium on Computer Science Education (SIGCSE '08)*. ACM, New York, NY, USA, 449–453. DOI: http://dx.doi.org/10.1145/1352135.1352287

[15] S Bocconi, A Chioccariello, G Dettori, A Ferrari, K Engelhardt, P Kampylis, and Y Punie. 2016. Exploring the field of computational thinking as a 21st century skill. In *Proceedings of the International Conference on Education and New Learning TechnologiesJuly 2016Barcelona, Spain Page*. 4725–4733.

[16] Stefania Bocconi, Augusto Chioccariello, and Jeffrey Earp. 2018. The Nordic approach to introducing Computational Thinking and programming in compulsory education. *Report prepared for the Nordic@ BETT2018 Steering Group. doi: https://doi.org/10.17471/54007* (2018).

[17] Karen Brennan and Mitchel Resnick. 2012. New frameworks for studying and assessing the development of computational thinking. In *Proceedings of the 2012 annual meeting of the American Educational Research Association, Vancouver, Canada*, Vol. 1. 25.

[18] Michael E. Caspersen, Judith Gal-Ezer, Enrico Nardelli, Jan Vahrenhold, and Mirko Westermeier. 2018. The CECE Report: Creating a Map of Informatics in European Schools. In *Proceedings of the 49th ACM Technical Symposium on Computer Science Education (SIGCSE '18)*. ACM, New York, NY, USA, 916–917. DOI:http://dx.doi.org/10.1145/3159450.3159633

[19] Hidden for Anonymity.

[20] Anita Ghai. 2019. *Rethinking disability in India*. Routledge India.

[21] Gwen Gordon. 2014. Well Played: The Origins and Future of Playfulness. *American Journal of Play* 6, 2 (2014), 234–266.

[22] Shuchi Grover, Stephen Cooper, and Roy Pea. 2014. Assessing computational learning in K-12. In *Proceedings of the 2014 conference on Innovation & technology in computer science education*. ACM, 57–62.

[23] Michael S Horn and Robert JK Jacob. 2007. Designing tangible programming languages for classroom use. In *Proceedings of the 1st international conference on Tangible and embedded interaction*. ACM, 159–162.

[24] Johan Huizinga. 2014. *Homo Ludens Ils 86*. Routledge.

[25] Maria Kallia. 2017. Assessment in Computer Science courses: A Literature Review. *Royal Society* (2017).

[26] Shaun K. Kane and Jeffrey P. Bigham. 2014. Tracking @Stemxcomet: Teaching Programming to Blind Students via 3D Printing, Crisis Management, and Twitter. In *Proceedings of the 45th ACM Technical Symposium on Computer Science Education (SIGCSE '14)*. ACM, New York, NY, USA, 247–252. DOI: http://dx.doi.org/10.1145/2538862.2538975

[27] Zuzanna Lechelt, Yvonne Rogers, Nicolai Marquardt, and Venus Shum. 2016. ConnectUs: A new toolkit for teaching about the Internet of Things. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. ACM, 3711–3714.

[28] Irene Lee, Fred Martin, Jill Denner, Bob Coulter, Walter Allan, Jeri Erickson, Joyce Malyn-Smith, and Linda Werner. 2011. Computational thinking for youth in practice. *Acm Inroads* 2, 1 (2011), 32–37.

[29] Stephanie Ludi and Tom Reichlmayr. 2011. The use of robotics to promote computing to pre-college students with visual impairments. *ACM Transactions on Computing Education (TOCE)* 11, 3 (2011), 20.

[30] Cecily Morrison, Nicolas Villar, Anja Thieme, Zahra Ashktorab, Eloise Taysom, Oscar Salandin, Daniel Cletheroe, Greg Saul, Alan F Blackwell, Darren Edge, and others. 2018. Torino: A tangible programming

language inclusive of children with visual disabilities. *Human–Computer Interaction* (2018), 1–49.

[31] Michael Palmer. 2011. Disability and poverty: A conceptual review. *Journal of Disability Policy Studies* 21, 4 (2011), 210–218.

[32] Venkatesh Potluri, Priyan Vaithilingam, Suresh Iyengar, Y Vidya, Manohar Swaminathan, and Gopal Srinivasa. 2018. CodeTalk: Improving Programming Environment Accessibility for Visually Impaired Developers. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, 618.

[33] Peter Seow, Chee-Kit Looi, Meng-Leong How, Bimlesh Wadhwa, and Long-Kai Wu. 2019. Educational Policy and Implementation of Computational Thinking and Programming: Case Study of Singapore. In *Computational Thinking Education*. Springer, 345–361.

[34] Andreas M. Stefik, Christopher Hundhausen, and Derrick Smith. 2011. On the Design of an Educational Infrastructure for the Blind and Visually Impaired in Computer Science. (2011). DOI: http://dx.doi.org/10.1145/1953163.1953323

[35] Amanda Sullivan, Mollie Elkin, and Marina Umaschi Bers. 2015. KIBO robot demo: engaging young children in programming and engineering. In *Proceedings of the 14th international conference on interaction design and children*. ACM, 418–421.

[36] Anja Thieme, Cecily Morrison, Nicolas Villar, Martin Grayson, and Siân Lindley. 2017. Enabling Collaboration in Learning Computer Programming Inclusive of Children with Vision Impairments. In *Proceedings of the 2017 Conference on Designing Interactive Systems (DIS '17)*. ACM, New York, NY, USA, 739–752. DOI: http://dx.doi.org/10.1145/3064663.3064689

[37] Ian Utting, Stephen Cooper, Michael Kölling, John Maloney, and Mitchel Resnick. 2010. Alice, greenfoot, and scratch–a discussion. *ACM Transactions on Computing Education (TOCE)* 10, 4 (2010), 17.

[38] Wikipedia contributors. 2019a. Right of Children to Free and Compulsory Education Act, 2009 — Wikipedia, The Free Encyclopedia. (2019). https://en.wikipedia.org/w/index.php?title=Right_of_Children_to_Free_and_Compulsory_Education_Act,_2009&oldid=911713004 [Online; accessed 20-September-2019].

[39] Wikipedia contributors. 2019b. Rights of Persons with Disabilities Act, 2016 — Wikipedia, The Free Encyclopedia. (2019). https://en.wikipedia.org/w/index.php?title=Rights_of_Persons_with_Disabilities_Act,_2016&oldid=913700612 [Online; accessed 20-September-2019].

[40] Oren Zuckerman, Tina Grotzer, and Kelly Leahy. 2006. Flow Blocks As a Conceptual Bridge Between Understanding the Structure and Behavior of a Complex Causal System. In *Proceedings of the 7th International Conference on Learning Sciences (ICLS '06)*. International Society of the Learning Sciences, 880–886. http://dl.acm.org/citation.cfm?id=1150034.1150162