My Robot can tell stories: Introducing robotics and physical computing to children using dynamic dioaramas

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***Abstract*—From time immemorial, stories have caught the fascination of young and old. Rural children in India, in particular, have a natural way of telling stories that are rooted in their heritage of social norms, values, and belief systems that are compelling and emotionally engaging. The process of writing and narrating their own stories enhances their verbal proficiency and makes them reflect deeply upon the story theme, thereby enabling them to develop higher-order thinking. In this research study, the author used stories to introduce physical computing and robotics to children in rural India in a personally meaningful manner. Children created interactive cultural dioramas based on classical stories from Indian folklore with robotic puppets that they programmed using the Scratch programming language. They learned 21st-century skills of creativity, communication, collaboration, and critical thinking by working in groups wherein they learned to divide tasks, manage time, work together, debate the pros and cons of different ideas, listen, think out of the box, and be active and engaged. The author observed that such an intervention improved the children's sense of agency and their interest in robotics and computational thinking. The author presents her results from pilot studies conducted in 2019 from two semi-urban schools in India on the children's perception of creating robots, programming, tinkering with electronics, career in robotics, and the workshop experience itself - all of which suggests that the children were deeply engaged and enthusiastic throughout the workshop making the entire learning experience a meaningful and joyful one for all. The results indicate that such culturally sensitive interventions can help children from collectivistic cultures embrace technology while preserving their traditional identities and cultural cohesion.**

***Index Terms*—STEM, Physical Computing, Robotics Education, 21st Century Skills, Middle School Education, K-12 education**

I. Introduction

Creating story narratives and telling stories is an activity that resonates with children of all ages. It draws even the most timid and shy children to become creative and express their life experiences in their unique way. When children work collaboratively on story authoring, it provides opportunities for an expanding dialogue that includes diverse viewpoints, thereby allowing for richer expressions. Advances in digital technologies have allowed for using a variety of media for creating collaborative story narrations. When children create story narratives using immersive technologies like Scratch [1], the process of story creation itself can help them build an understanding of computation. In this research study, the author documents and shares lessons learned from blending story creation with physical computing and robotics by creating interactive dioramas that allow children to make technology artifacts' that are situated in their cultural values and beliefs.

With the current education structure in India, school environments that foster open-ended design-build projects are uncommon, especially in rural India. United States and several countries in the west have integrated engineering, technology, and 21st-century skills into the national framework for K-12 science education for over a decade [2]. But this effort is starting to gain momentum only with the recent National Education Policy 2020 [3] in India that attempts to revise and revamp the education structure. While on the one hand, education restructuring has been slow to come, and the implementation of this policy is still awaited, on the other hand, rural and semi-urban schools continue to be crippled by insufficient financial resources, antiquated technology infrastructure, and inadequately trained teachers to impart technology education. Public schools in remote rural villages still have combined classrooms for multiple grades let alone have a basic computing facility that is open for children to access [4]. In the more developed village and semi-urban schools, there are computer rooms with about 20-30 barely functional computers for children to work with. But the teachers are overburdened with teaching and administrative duties [4]. Hence the children are only taught basic computer applications like word processing, spreadsheet, and presentation applications. In a prior research study [5], the author and her co-workers had surveyed technology fluency among the children and found that less than 50% of the children know how to take printouts, do spell checks on documents, or record sounds on a computer.

Since the demographics the author was working with are much like the inner-city youth that Resnick describes in his idea of setting up computer clubhouses, she draws her inspiration from that work and attempts to convert the computer rooms in rural schools into spaces that can support learning through design experiences [6]. Her approach to bringing in design experience and 21st-century skills was to conduct informal maker workshops in these spaces that are transdisciplinary and yet have their foundations on familiar concepts.

Traditionally, dioramas made by children in schools are 3-dimensional static models on a certain topic of an academic subject, typically on science or an event in history. The act of creating a diorama helps learners have fun and provides a collaborative learning experience using low-cost art supplies. It gives space for creative and aesthetic expressions. The author built on this conventional idea to evolve dioramas into a dynamic, interactive, and cultural story space. She chose diorama construction because it serves as a means to integrate arts, spatial thinking, and physical computing viz., tinkering with electronics, programming, and computational thinking. In this article, the author has used the terms ‘physical computing’ and ‘robotics’ interchangeably. The author does acknowledge that the terms physical computing and robotics are different concepts, although closely related - the former focuses on creating tangible artifacts that interact with the real world while the latter focuses on autonomous actions. Since the skills needed for both are similar and also since the children were more familiar with the term ‘robots’ from cinema than with the term ‘physical computing’, she has used them interchangeably.

The purpose of this research study was to determine children’s perceptions about this informal workshop. To understand this, the author asked the question: How do short-term STEM workshops for children from under-represented communities influence the children’s perception of robotics and physical computing? Previous researches done in the west on STEM perceptions report that STEM perceptions will be affected by student’s engagement in STEM activities, their interest and motivation, their intentions to persist with STEM, their self-efficacy, and their experience in group activities [7], [8]. Meyers et. al discuss opportunities created by informal learning spaces for lifelong digital technology learning [9]. Such spaces have the potential to ignite interest in STEM and STEM careers even for those children who might not find formal science classes engaging. Therefore, for this empirical study, the author based the selection of tools on the premise that the inclusion of a variety of tools would provide the children with a plethora of interesting project options and allow for more creative and fascinating projects, thereby enabling them to have a powerful lived STEM experience.

In the next section, the author describes some of the prior research done on interactive storytelling technologies for children. The third section briefly provides the theoretical framework of constructionism on which this research is based. The fourth section presents the structure of the activity-based learning workshop. The next two sections touch upon the research study design. The author then presents her observations, results and learnings from conducting the workshops. She concludes the paper with avenues of future work.

II. Prior research

Over the last two decades, several interactive story authoring that spanned digital and physical realms have been designed with different research goals. This includes authoring tools for stories using robots where the focus was to help primary school children create story narratives as well as authoring tools that focused on teaching children both story creation and computing.

Let us first discuss research done on story authoring tools for young children. Using the cooperative inquiry model, Druin et. al [10], [11] co-designed Personal Electronic Teller of Stories (PETS), a huggable robot designed to look like an animal to help young children create and tell stories. This research focused on the inter-generational participatory design process itself where children played the role of design partners. StoryRooms described the physical storytelling experience of authoring room-sized interactive stories [12]. They were again built by intergenerational teams to create collaborative storytelling and story-building spaces. In another work, Ryokai and Cassell designed StoryMat to support storytelling and collaborative fantasy play [13]. The authors shared that the StoryMat provided a place that fostered developmentally advanced storytelling with children as narrators. Stal et. al discussed the use of the Cozmo robot to provide a structured story-based play wherein the robot toy’s expression of emotions influenced children to incorporate emotions into their stories [14].

One early work in authoring tools for children that supported both story composition as well as computing was ‘MOOSE crossing’ where children created text-based story narratives using the Moo language [15]. Kelleher and Pausch introduced ‘Storytelling Alice’ for story creation by programming 3D animations using block-based programming to support positive experience in computer programming for girls [16], [17]. Burke and Kafai explored children creating story narratives through informal play using Scratch [18]. Ryokai et. al helped children create their personal stories by drawing props and programming the behavior of a robot named Pleo to respond to the props and physical touch [19].

These articles provided insights on how the author could sensitively introduce computing to children and blend story creation to help children have personally meaningful experiences. It must be noted that the author’s work was with an older age group of middle school children. Yet due to their limited technology fluency, she needed to start them out with a very simple programming environment that was easy for the children to get started with and yet allowed for ‘big ideas’. Researchers from her research lab had introduced computational thinking and game design using Scratch in a previous work [20]. In this work, she built upon children’s basic knowledge of block programming using Scratch to help them create stories and robots with physical computing.

III. Constructionism and Physical Computing

Jean Piaget theory of constructivism asserts that learners construct new knowledge and understandings by reflecting upon experiences and accommodating new experiences from their prior knowledgeable base. Thus the knowledge learners already know helps them construct new knowledge. Seymour Papert built upon this idea and suggested that by actively engaging in building tangible artifacts, learners connect ideas and acquire knowledge. Thus, the discovery of knowledge is student centered and not teacher centred. This forms the theoretical background for this research study.

Physical computing allows for learning by constructing ideas with computers in physical terms to make personally meaningful story constructions, the central tenet of constructionism [21]. In Papert's own vision [22],

> *In our image of a school computation laboratory, an important role is played by numerous "controller ports" which allow any student to plug any device into the computer... The laboratory will have a supply of motors, solenoids, relays, sense devices of various kids, etc. Using them, the students will be able to invent and build an endless variety of cybernetic systems.*

And as O'Sullivan and Igoe [23] stated in their seminal work on physical computing

> *Physical computing is a nice pedagogical tool for teaching general programming concepts because it naturally causes people to imagine the program's tasks in physical terms.*

Thus, physical computing lends itself to the creation of interactive objects and installations as well as addressing theoretical and technical aspects of computer science [24] making it an ideal platform for blending storytelling and computing. Bull et. al explored this intersection of physical computing and story creation in their work on Storymaking [25] where the children learned several key concepts in computer science, engineering, and literacy. They reported that children could develop collaboration and communication skills using technology as a means for personal expression.

IV. Workshop structure

The workshop design was an application of instructionist-constructivism [26], [27]. Two co-workers helped the author conduct the workshop in schools. The team presented new concepts about physical computing to the children through a carefully planned, instructor-led curriculum over the first two days. Into this, they mixed in two short (half an hour) and two long (one-two hour) periods of self-directed and group-based learning activities. The final project on the third day of building the dynamic diorama was planned as a constructionist activity that was completely student-led. In this way, the researchers tried to blend the core values of constructivism viz., *student-centered instruction, meaningful learning, active student involvement* and *student personal satisfaction with learning* with the core values of instructionism viz., *systematic, teacher organization* and *specific learning objectives* to provide developmentally appropriate learning for children from a primarily instructivist culture [26].

A. Introducing children to physical computing with flexagons

The icebreaker to begin the three, sometimes four-day workshop was to introduce the children to creative flexagons. Flexagons are made by folding paper in certain patterns which when flexed reveals hidden faces. This tangible activity of making flexagons started the workshop on a fun note. Into the flexagon activity, the researchers weaved in the workshop theme of environment protection and conservation. They asked the children to convert their flexagon into a storytelling contraption [28]. The children drew scenes on each face of the flexagon or wrote short captions on each face to describe a story scene. With each flex, a new scene was revealed.

B. Creating tangible technology artifacts

The researchers introduced the children to electronics circuits using the Hummingbird circuit boards created by Birdbrain technologies [29]. They chose this circuit board because it supported open-ended projects based on Scratch. This interface made it easy for the children to learn how to connect sensors (distance sensor, light sensor, etc) and actuators (DC motors and servos) using learning materials that the research team had developed as a part of the Amrita Svasethu robotics kit [5]. The kit (shown in Fig. 1) consisted of

1) Hummingbird duo robotics kit from Birdbrain Technologies
2) Modular curriculum with audio-visual teaching aids on scratch programming and hummingbird kit connections
3) A collection of stencils for creating paper-bots with folding and assembly instructions
4) Assortments of laser-cut paper props for creating scenes on nature theme
5) Stationery including foam boards, paint, glue gun, etc for making the props and table-top dioramas

For a span of 9 hours spread over 2 days, the children worked in pairs to cut out the stencils and assemble their paper robots. The children chose the stencil they wanted to work with. They cut and folded the stencils and wired motors and sensors into the stencils to form their paper robots. They programmed small movements for their robots with the Hummingbird controller and Scratch. For example, the elephant robot could move its head up and down and the girl robot could swivel her body.

C. Building empathy with debate

To encourage children to explore, research and understand the workshop theme a little deeper, the researchers gave the children a magazine article to read about how mass killing of elephants psychologically affects the pachyderms [30]. They then organized a debate in which they divided the workshop participants into two groups and assigned opposing topics to the groups - the topics were:

- Elephant habitats are being threatened. It is the role of the government to protect elephants.
- Elephant habitats are being threatened. It is the role of each one of us to protect nature and the elephants.

The teams were asked to research both sides of the argument as a take-home assignment. On the following day, the researchers organized a debate in three rounds. The children were asked to present to an audience of teachers who also formed the

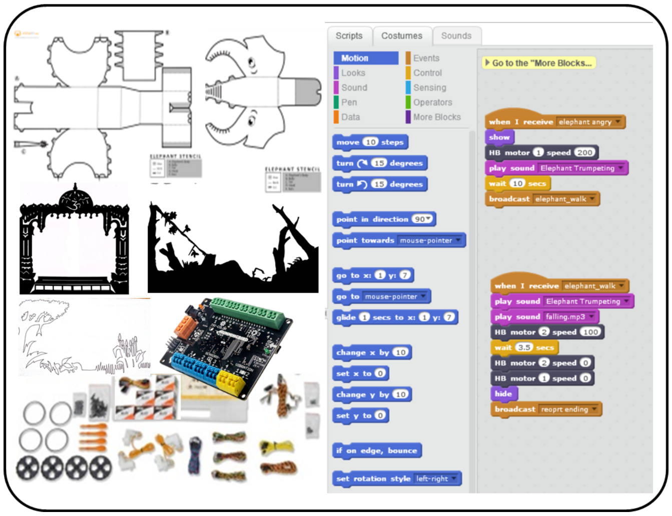

Fig. 1. Amrita Svasethu Robotics kit including modular curriculum containing student handouts, stencils, laser cut props, assessments and rubrics. The researchers have created two versions of the kit, one with the Hummingbird circuit board and the other with the BBC Micro:bit

judging panel. The children were told that they must win the support of the judges to win the debate. In the first round of the debate, each team was given 20 minutes to discuss among themselves the points they had researched and present three points in support of their position to the judges. Each team was instructed to practice listening to the opponent team and take notes. In the second round, the teams were given 20 minutes to come up with counterarguments for the points raised by the opponents in the first round and present them. This was to ensure that the children had not just heard the arguments presented in the first round but also tried to understand them. Finally, in the last round, they were asked to provide a concluding statement for their position.

D. Blending story creation, physical computing, and robotics

The researchers presented the children with a video of a diorama story called “Save the elephants!”. The video showed a story that was divided into three scenes. Each scene was depicted through a dynamic diorama that the researchers constructed and filmed prior to the workshop. The first scene started with a young child watching the television where she sees elephants trampling down crops, pulling down trees, and running amok in a village. The child is disturbed by what she sees and wonders loudly why elephants are causing havoc in the villages. The story transitions to the second scene where the girl is in a village temple. She explains her confusion to the presiding deity who has an elephant head. She asks him to tell her his story of how he came to be and why he chose to adorn the head of an elephant. He recounts his story from Indian mythology and tells her how elephants have always enjoyed an elevated standing in Indian culture and traditional practices. The story moves to the third and final scene where the deity continues talking to the child about the destruction humans have caused to the delicate forest ecosystem and how this has resulted in habitat loss, degradation, and fragmentation of the elephant species. The story ends with a message to protect the elephants as a collective responsibility.

The researchers encouraged the children to either choose to retell the same story in their dioramas or author a new story on the theme of environmental protection and conservation from an Indian cultural perspective. Since the dynamic dioramas involved several steps to create them, the children were asked to group themselves into teams of six for working on one dynamic diorama. The team had to split all the following tasks among themselves so as to complete creating the diorama in one day

1) Planning the role of each team member
2) Scripting and storyboarding the story
3) Recording dialogues for the story
4) Animating a backdrop for the diorama
5) Wiring the motors and sensors as well as programming the robot movements
6) Painting and assembling the props
7) Presenting the diorama to parents, teachers, and other school children

V. Participants

In 2019, the research team replicated this workshop in five schools in Kerala, India. In this research study, the author has presented her findings only from the first two workshops. For several implementation reasons, the other three workshops were conducted as combined workshops with other STEM workshops for the same cohort of students. Since the findings from the combined workshops cannot be attributed to this research study alone, the author has analyzed data only from the first two stand-alone workshops.

The workshops were conducted over three days in each of the two schools. 12 girls and 34 boys attended the workshops. 29 children attended the first workshop and 17 children attended the second workshop. All children who participated were between the ages of 11 and 14.

VI. Evaluation Method

To answer the research question, the author collected feedback from the children about the workshop. At the end of each day of the workshop, as a part of daily reflections and feedback, the author asked the children to describe what they liked/did not like about what they learned that day. At the end of the first workshop, one of the school teachers spontaneously asked the participants to share their impressions on the workshop including what part of the workshop they found most useful and why, what part of the workshop was least useful to them, and why, and what recommendations they had to share with the researcher about the workshop. Nine children provided handwritten feedback which was also included in this analysis. The author collated all the participant reflections from both schools into a single document. This gave me a total of 97 feedback snippets.

To draw out meanings children attributed to their lived experience of experiential learning, the author used an iterative inductive approach to perform qualitative analysis. She carefully read the raw feedback several times before she began coding. She took each feedback snippet and assigned descriptive codes that have a close connection to the research question and captured the essence of their experience. She reviewed all the codes and grouped those that shared similar properties and removed redundancies. Complex themes emerged as she began grouping the codes.

She also performed a sentiment analysis on feedback data to gather an understanding of children's emotions. To analyze the sentiments and understand how the children felt about different parts of the workshop, she first created categories based on the main workshop components. She labeled the topics they touched upon while expressing their opinion based on keywords the children mentioned in their text. So if the children talked about electronic components like LEDs, motors, sensors, etc, she categorized it as "Tinkering with electronics". She used a popular web-based sentiment analysis service Monkeylearn SaaS platform [31] to perform the initial classification into positive, neutral, and negative sentiments. The software provided 84% accuracy in classification. She manually fixed errors in the software's classification for statements such as *"Actually I loved everything [about the workshop]. I didn't hate anything"*. The software misclassified this statement as a negative sentiment because of the use of the word 'hate' which the author corrected.

VII. Observations about the dynamic diorama creation project

Jackie Gerstein discussed five stages of making that children go through when working in maker spaces [32]. In the workshops, the researchers observed a similar evolution of making stages (as shown in Fig. 2). In the first two days of the workshop, children mostly stayed in the copy and advance stages. They did all the activities as per the instructions and some fast learners went on to do the stretch tasks. But on the third day, the research team could see children move to the more advanced making stages. Almost all teams decided to retell the story of "Save the elephants". However, all the groups added several creative embellishments to their puppets and props. For the story narration, some groups modified and expanded upon their previously created animation sequences for the backdrop of their diorama whereas others created new animation sequences. One team wrote their own personal story about climate change and protecting planet earth through responsible consumption. They added quotes from the Indian scriptural text of the Bhagavad Gita into their story. Thus, although only one team actually reached the Create stage in interactive story creation, several teams added uniqueness and differentiation to their stories thus almost reaching the Create stage.

a) Scripting and storyboarding the story: The teams chose the robot characters they wanted to use in their story from the robots they had made in the first two days of the workshop. They scripted their own dialogues for the robot characters. Some teams needed to watch the demo video a couple of times before they got started with scriptwriting while other teams dove right in, adding their own touch to the story script. Their personalized versions reflected their understanding of environmental responsibility based on the Indic cultural values they had imbibed from their school and their communities.

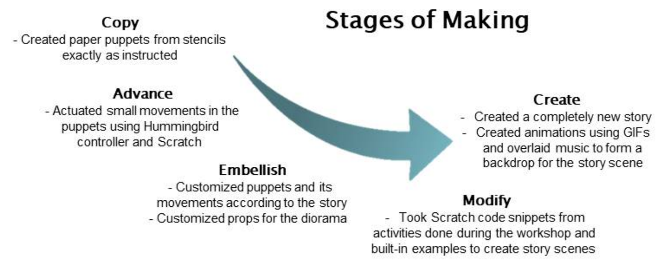

Fig. 2. Stages of Making that the children went through. Adapted from Becoming a Maker Educator [32]

The researchers observed that in some teams, one or two children took a leadership role and delegated tasks to all their team members. In some teams, some children picked out the tasks they wanted to do and let the others in the team divide up the rest of the tasks. The researchers also observed that this step got quite animated with teams that did not have a clear leader or a clear task division strategy. The story scripting process took a long time to complete since they had to do a lot of negotiations, discussions, arbitration, and conflict resolution among team members. This slowed the team's progress on later tasks. While this might be seen as having had a negative impact on the team in terms of task completion, the author believes that those teams that had significant conflicts learned very important life lessons.

b) Recording dialogues for their story: Almost all teams did this step in parallel with the other steps. Since the classroom where the workshop was being conducted was quite noisy and chaotic with lots of movements, the teams selected one or two members from their team to go to a quieter place in the school to do the sound recording. The children borrowed mobile phones with a voice recorder app from the instructors to record the dialogues. With the instructors' help, they learned to transfer the recorded sounds onto their computers which they subsequently loaded into the Scratch programming environment.

c) Animating a backdrop for the diorama: The children downloaded GIFs and images from the internet for creating an animation sequence for their story scene. In one school where the internet connection was not stable for all children in the workshop to access the internet at the same time, the researchers provided the children with a collection of images and GIFs that they downloaded prior to the workshop and copied it locally onto the children's computers. The children picked images and GIFs from this local cache. The children applied their knowledge of creating animations they had learned on the preceding two days to animate their story scene. They interleaved music and dialogues they had recorded into their animations. The animation on the computer monitor served as a backdrop for their dynamic diorama, thereby providing a theatrical stage setting and effect.

Fig. 3. Top: Children assembling the props and programming the Hummingbird circuit board to make their diorama. Bottom: Children presenting their diorama to an audience consisting of peers, teachers, parents, and scientists from the local community

d) Wiring the motors and sensors and programming the robot movements: This step needed to be done in close coordination with the previous step, which was to animate a backdrop for the diorama. The researchers observed that typically, children worked on different computers, one to code the animation sequence and one to code and test out their robot movement. When they were finished, they would manually merge their program for robot movements with the animation sequence program. The researchers observed that none of the teams planned for intermediate sync points between the two programs. Hence they ran into synchronization issues when they integrated the robots into their animation sequence. The backdrop animation would ‘move ahead’ or ‘lag’ and get out of sync with the robot movements being enacted in the foreground on the diorama. During this phase, the three researchers would walk around the room asking children to describe what they were doing and if they needed any feedback or assistance. In one of the schools, one child approached the researchers seeking help to resolve the synchronization issue. The researchers showed him and his team some advanced concepts of event handling and message passing in Scratch for coordinating different parts of program execution. Soon other teams also wanted to learn the same techniques - they didn’t want to be ‘left behind’. The researchers encouraged the children who knew how to resolve the issue to show the children who wanted to learn. Soon many teams were implementing event handling and message passing in Scratch. It was wonderful to see how quickly the children learned from each other. The researchers encouraged the children to keep up the peer interactions, with children teaching and learning technology-related concepts to each other even after the workshop. Some children expressed skepticism about the possibility of continuing collaborative learning after the workshop stating that their regular classes were primarily teacher-led and hence did not permit such group work. The researchers acknowledged this limitation but encouraged them to keep tinkering every time an opportunity presented itself.

e) Painting and assembling the props: In this step, the children created the physical tabletop diorama. The children painted the paper props to create a scene for their story. The children spread out around the room, typically using up all the floor space in the classroom to do the painting. This activity became quite messy at times as well with children mixing up paint colours and getting the paint on their school uniforms. After painting, the children arranged the props in layers on the diorama base. They then placed their robotic puppets into the scene. Most teams were content to just assemble everything together before their presentation, but a few teams carefully routed the wires to conceal the wiring to LEDs and motors to enhance the aesthetic appearance of their diorama. Some teams layered many props to make their diorama very visually appealing whereas others kept the props to a minimum. It was interesting to note the different variations and originality children brought into their diorama

f) Presenting the diorama to parents, teachers and other school children: The conclusion of the workshops was marked by an exhibition of the children’s work. The researchers invited parents, teachers and other school children to view the dynamic dioramas. This was a highlight for the children. They enjoyed all the attention they got and enthusiastically shared their story with others.

VIII. Results and Discussion

A. *Qualitative analysis of student feedback*

Looking at the research question from a constructionist lens, from the inductive analysis four main overarching themes emerged from the data. The workshop a) promoted meaningful learning b) promoted engagement and c) developed higher order thinking skills d) built aspirations. In the following sections, the author elaborates on the themes with examples of quotes from the children. All names are pseudonyms and not the original names of children who participated in the study.

a) Meaningful learning: The author derived three subthemes for this overarching theme which includes "fostering a sense of efficacy," "promoting learning towards a collaborative goal," and "providing a sense of purpose to learn" which is supported by prior research in constructionism based coding activities [36].

Fostering a sense of self-efficacy is one way of constructing meaningful learning. According to Bandura, self efficacy is the conviction one holds about his or her ability to execute behaviours that is required to produce specific performance accomplishment [33]. Abhi shared that the workshop bolstered his sense of efficacy by sharing *"First in the beginning I don't know nothing about what is robotics but now if any one asks me about robotics I would answer it simple and also I learnt not all but the 1st step of robotics"*. Akshay said,

> *It is because when I came to the workshop I was uncertain to do the work. On the first day they teach me to connect the things and to program and 2nd day I do the thing they teach on the 1st day and on the 3rd day I and my partner do it with an happy manner.*

In other words, group-based projects such as the dynamic diorama project created an environment for children to develop a sense of collective efficacy. The collective efficacy helped them to support each other and apply their learning towards a collaborative goal. The feedback also suggests that the cycle of belief in themselves and their own abilities, their collective actions and achievement created a sense of fulfilment in the children. Adi expressed *"I participated in the robotics [workshop] because I wanted to make a flyer which will make me fly. I liked it very much as it was interesting. I became more intelligent and creative by participating in this workshop"*.

Children expressed a sense of purpose to learn physical computing. Aswin stated that it was important for him to learn robotics. *"I like robotics and like to learn more about it. So when I get a chance to learn, I never ever miss it. For how much I studied about it, it [was] enjoyable and great"*. Thus the children used the opportunity they got to learn robotics and physical computing through hands-on tinkering to develop competencies for a personally relevant purpose.

b) Engagement: The engagement theme included the following sub-themes: "feeling excited," "being proud of one's work and wanting to make it visible," "learning to work in a team," "expressing one's desire for continuing this experience" which is again consistent with research on technology supported learning based on constructionism [36], [37].

Since this was the first experience most children had with physical computing and robotics when they got their circuits working, the children were thrilled and excited. Reshma reflected upon this experience,

> *The reason I liked [the workshop] was because I have learned how to make robots. I never thought that we could create a lot in Scratch. It is very fun. It is an miracle when the sensor sensed our hand.*

The students were very proud of their work and wanted to celebrate their achievement by making it visible to their school community. Arjit stated *"The class was so creative and great, I learnt about flexagon, hexaflexagon, more coding in Scratch, about the kit, introduction to robots and other components. I enjoyed this class. I hope there will be an exhibition from this Robotics class"*. When the children saw how much they could achieve in a matter of three days by working together in teams, it was a remarkable experience. Meghna shared *"I was introduced to robotics making and programming them. More importantly I learnt how to work as a team"*.

Aman agreed with Meghna saying *"I liked how we cooperated and worked together to work out things"*. Thus practising the 21st century skill of collaboration became a natural part of their activities during the workshop.

Several children expressed their desire for continuing this experience. Mahesh shared *"I knew that robotics will be fun to do and that was real. But I am very sad the class is over. Next year you have to extend the days"*. Soorya articulated *"I liked it so much. I would like this workshop conducted everyday"*. All these feedback suggest that the opportunity the children got to work with physical computing and create physical stories was deeply engaging and a powerful experience for them.

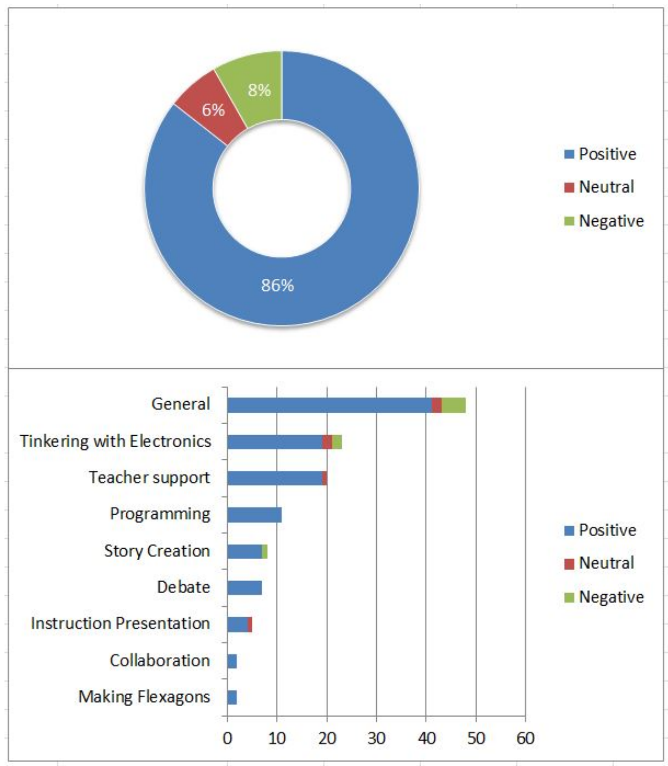

Fig. 4. Sentiment analysis on children's feedback. Top: Overall sentiment about the workshop. Bottom: Sentiments about different components of the workshop

c) Higher Order Thinking Skills: The author derived two subthemes for this overarching theme which included "learning physical computing" and "participating in a debate". For creating the dynamic diorama, the children had to put several critical thinking and creative skills they learnt during the workshop into practise. Consequently, children's personal sense of agency and mastery over physical computing and digital technology was raised. Keshav expressed,

> *I got to make a moving robot. I learnt every tool like the microcontroller, servo motor, gear motor, LED and tri LED lights, sensors, etc. I also learnt how to code using Scratch. The class was informative and entertaining, I am excited about the next session where we build our own story.*

In order to debate, children need to critically analyze an issue viz., they need to conduct online research, synthesize, analyze and interpret information and present it coherently and succinctly. The children never participated in an in-class debate before. So it was a novel experience for them. Lakshmi shared *"From the debate conducted during the session I learned a lot of things like how to prepare for a debate and about many different things the government has done and not done for the country and many more"*. Krishna further added,

> *I like and loved to debate each other without arguing. I learned a lot from this debate. When I got this point or topic only I was able to think more about elephants, forest and government. This helped me to learn more on forest, nature, people, government etc.*

Dev agreed saying, *"The debate was so nice. I learned what a debate is. I also enjoyed it. I also learned about elephant habitat threatening and much more"*. Thus, including structured debates in the workshop helped promote critical thinking, improve communication skills as well as provide an intrinsic motivation to learn [35].

d) Building aspirations: The children, being in middle school, were in the transitory age group where agentic actions shape their current and future identifies. In their feedback, children expressed future-orientated thoughts. Megha said *"I think we should continue this robotics activities with the help of our science labs. Robotics is a new branch of science, we should be aware of the innovations taking place around the world. School library can assist us by introducing books based on robotics"*. Mehandi agreed,

> *I really liked the robotics class. The robotics class helped me to know more about robots. I think it will be more useful for my future.*

It gave them a chance to imagine the possibilities of what they could build in the future. Lakshmi shared, *"The workshop has created interest in me regarding the topic robotics and helped me in exploring more about robotics. It has helped me in creating a dream in me of building a robot which will be useful for mankind"*.

B. Sentiment analysis on student feedback

Fig. 4 shows the results of the sentiment analysis. Overall sentiments about the workshop were largely positive. Over the course of three days, most children mentioned positive sentiments about tinkering with electronics and programming. Children also expressed positive feedback on the story creation component. Based on the author's learnings on student engagement from another workshop that the author conducted in 2019 on Sustainable Development Goal education, she will be adding game-based learning assessments using the Kahoot! learning platform into future workshops [34].

IX. Conclusion

Each child's life experience shapes their unique perspective of life based on how they understand what happens around them. This allows for a myriad expression of stories based on how the child chooses to say it. The question we sought to answer through this research study was: How do short-term STEM workshops for children from under-represented communities influence the children's perception of robotics and physical computing? The results indicate that a collaborative effort on story creation in the form of dynamic dioramas could give every child an opportunity for learning 21st century skills including creative problem-solving, communication and collaboration. They learn computing in the process of authoring stories - learning computing, therefore, becomes a tool for expression rather than an end in itself. Blending cultural themes into computing education adds to the richness of the experience and situates it in the lives of the children thereby making it personally meaningful.

While organizing constructionist workshops in rural and semi-urban schools in India is fraught with logistical challenges, this informal workshop suggests that even short duration workshops can provide powerful lived experiences for the children. The results suggest that it promotes a learning experience that is deeply engaging, develops a higher sense of self efficacy, and builds children's STEM aspirations. Building a tangible technology artifact such as the dynamic diorama raises their personal sense of agency, achievement, and control over digital technology. The experiences shared by the children in their feedback from the workshop also suggest that the workshop helped the children practise and become familiar with the 21st century skills of critical thinking, communication, collaboration and creativity and helped them advance their learning about robotics and its relevance for their own future. Further research should be undertaken with a larger student population to generalize the results.

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