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Research Paper

User experience testing and co-designing a digital game for broadening participation in computing with and for elementary school children

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A R T I C L E I N F O

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A B S T R A C T

Broadening participation in computing is more than providing access to computing for students; it requires reimagining and transforming teaching and learning to be more inclusive and culturally sustaining and it begins with elementary school children. In this study, we report on the fourth cycle of a participatory design-based research project in which researchers and children co-design culturally responsive-sustaining computational learning environments. We conducted user experience testing and co-design sessions with seven children on one level of a game-based learning environment in development. We model children's discourse through Epistemic Network Analysis models to investigate their feedback on character design, game narratives, and introductory activities. Our findings reveal 1) children's positive response to characters with counternarratives and visible intersectional identities in computing, 2) positive and negative experiences and feedback from children on game activities and narratives, and 3) suggestions for improvement.

1. Introduction

Computational thinking skills are fundamental for students of all ages. In an increasingly digital world, students will need skills for systematic problem solving, understanding complex systems, and creating algorithms (Barr et al., 2011). However, in the United States, access to computer science educational experiences is dependent on race, ethnicity, gender, socioeconomic status, and other intersectional identities (Means and Stephens, 2021). Black, Latinx, and Native American children as well as those who live in poverty or have disabilities face adversity to participate in computer science. These challenges include lack of funding or school resources, non-relevant or non-engaging curriculum (Goode & Margolis, 2011; Kafai & Burke, 2014), and social or psychological barriers from being a member of one or more marginalized groups (Margolis, 2017; Ong et al., 2011). Such inequities in computer science education are situated within broader historical systems of oppressions across social institutions, including educational institutions (Freire, 1970). Thus, to broaden participation in computing, providing access to all students is not enough. Researchers and educators must work towards designing and offering meaningful participation in computing that aligns with the multiple ways of being and knowing of marginalized youth that have been rendered invisible for years (Margolis et al., 2012). Such computing education should begin at the elementary school level (Rich et al., 2019).

However, engaging elementary-school aged children in computational thinking in diverse and culturally responsive ways requires developmentally appropriate design considerations. Moreover, to connect to marginalized children's varied lived experiences, it's important to include children as co-designers of emerging technologies for new digital literacies. Thus, in this study, we report on the fourth design cycle of a broader participatory design-based research project on co-designing culturally responsive computing experiences with and for children. In this cycle, we have co-designed a digital game for upper elementary-school children, ages 7–12, to engage in computational thinking through role-play and narrative engagement. This study reports on user experience testing of one game level and a post testing co-design session. Our research questions are: (1) How do children interact with a game-based learning application grounded in culturally sustaining computing frameworks? (2) What are children's design ideas after testing the game-based learning application?

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2. Theory and background

2.1. Game-based learning

Decades of research in digital game-based learning have demonstrated positive outcomes in terms of increased motivation and outcomes for content learning (Herro et al., 2013; Tobias et al., 2014) and continues to do so for elementary school-aged children (Hussein et al., 2019; Partovi & Razavi, 2019) and in computer science (da Silva & Silveira, 2020). Digital games provide students with the skills to make quick decisions (Prensky, 2001), collaborate (Gee, 2003), create strategies to overcome obstacles and solve problems (Cicchino, 2015), and think critically (Shaffer, 2006). With the support of advanced technology, games allow for implementing instructional strategies in learning, support students' acquisition of knowledge to achieve learning goals, and allow them to customize learning based on their own skill levels and learning styles (Hwang & Chen, 2022).

The forms of learning that take place in games align with Vygotsky's ideas around imaginative play (Vygotsky, 1978). For children, engaging in play is a way to rehearse new and complex social concepts in low-risk environments. For example, children may play "family" together in their own homes and role-play as mothers, fathers, children, and other family members to experiment with boundaries and rules around acceptable social interactions. The toys and tools that children use are culturally and socially constructed artifacts that help children learn about the world around them. Through the lens of play, game spaces with purposefully designed tools and activities for exploration can be impactful developmental opportunities. For example, game-based narratives and stories can engage and immerse children in socially constructed activity (Adams et al., 2012). For learning purposes, scaffolds, activities, documents, and other tools can be embedded into a narrative to motivate children through the game and provide a cohesive context for participation (Arastoopour Irgens, 2019; Barab, Gresalfi, & Ingram-Goble, 2010; Barab, Gresalfi, Dodge, & Ingram-Goble, 2010). The flexible technical design parameters that game-based learning offers can be especially beneficial for children of color if the digital spaces foreground Black and Brown characters, narratives, and visions (Chang et al., 2021). Designers of learning games can choose to incorporate characters who intersect at multiple marginalized identities. An *intersectionality* lens views race, gender, class, and other categories as interrelated and how such intersecting identities affect individual and social power dynamics (Collins & Bilge, 2020). Moreover, these characters can play roles in *counternarratives* which make visible the stories and experiences of marginalized populations whose stories are often not told (Ladson-Billings & Tate, 1995; Solórzano & Yosso, 2002) and compete with more dominant cultures. Thus, the use of intersectional identities and counternarratives in game-based environments creates a sense of belonging for children who have been historically excluded or stereotyped in such spaces (Gray, 2020).

Games and digital learning spaces also have the power to support multiple forms of expression engagement from students, allowing broader participation from more students (Cunningham & Murphy, 2018). If the adult facilitators and the tools themselves support opportunities for different avenues of expression, children can explore ways that computing can support their lived experiences and topics that matter to them and their communities (Roque et al., 2016).

2.2. Broadening participation in computing

Because of the opportunities to create counternarratives and make intersectional identities visible in computing, game-based learning environments can support broader participation in computing. However, such game design should be grounded in frameworks that support meaningful participation for those who have been historically excluded from computing. Kafai and Burke (Kafai & Burke, 2014) argue for leveraging the cultural practices of girls and other excluded populations to reimagine what participation may look like rather than simply giving access to the same traditional educational models and experiences. Rankin and Thomas (Rankin & Thomas, 2020) argue that to imagine broader participation, we must consider the nuanced intersectionality of students' identities and the power structures that are at play. When educational tools that teach about sociotechnical systems are designed from an intersectional perspective, it can empower girls and women of color to become agentic, critical users and producers of technology (Garcia & Scott, 2016; Noble, 2013).

Following this line of scholarship, the *culturally responsive-sustaining CS education framework* (Kapor Center, 2021) was developed by a team of researchers, practitioners, and students and is grounded in decades of culturally relevant pedagogy research from multiple disciplines. The framework contains six core components for creating inclusive computer science educational environments (Fig. 1). The goals are to embrace and validate students' interests, identities, and cultures while facilitating students' knowledge of computing content. Furthermore, students should learn how to engage in sociopolitical critiques about technology and its impact on various populations.

3. Methods

3.1. Participatory design based research

In traditional design-based research, the goals are to 1) ground experiments of learning interventions in theory and implement in naturalistic settings and 2) generate new theories of learning to explain phenomena and produce change in the world (Barab & Squire, 2004; diSessa & Cobb, 2004). *Participatory* design-research reimagines this approach by paying attention to what forms of knowledge are generated, how, why, where and by whom, and focuses on generating new theories for sustainable social change (Philip et al., 2018). These additions challenge power dynamics and reconfigure partnerships such that knowledge from all participants is valued and distributed in research and design (Bang & Vossoughi, 2016).

Involving children in participatory design-based research offers valuable benefits that empower children to have agency in their learning and foster a sense that they are heard and can influence and participate in their own education (Jones & Bubb, 2021). Children have different lived experiences than adults and are experts in what it means to be a child today (Guha et al., 2013) and thus, can influence the design of technologies and learning experiences that are relevant for them and improve the usability of tools and learning spaces (Bonsignore et al., 2013). Intergenerational participatory design work, however, is inherently encased in complex power dynamics among children and adult researchers (Cumbo et al., 2019; Guha et al., 2013). Researchers have encouraged critical reflexivity and provided checklists of ethical practices when working with vulnerable populations of children in participatory design (Read et al., 2013). Others have encouraged a practice of micro-ethics during design with children such as paying attention to turn-taking in discussion, building relationships between adult researchers and children while also setting boundaries, and negotiating multiple agendas (Spiel et al., 2018). With children specifically, research has shown that engaging in play during participatory design can encourage children to voice their ideas more readily and increase children's voice in the design activities (Schepers et al., 2018).

This study stems from five years of participatory design work with children in community after-school centers in which we tested and retested a critical computational educational program designed to help children understand sociopolitical issues surrounding bias in AI technology and reflect on ways to mitigate such biases in the future (Famaye et al., 2024; Arastoopour Irgens, Adisa, et al., 2022; Arastoopour Irgens, Vega, et al., 2022). The data-based input we received from the children during each iteration of the study provided insight into the future design of the next iteration of our research. By using the children's input in continuous redesign of the activities, they became co-collaborators and

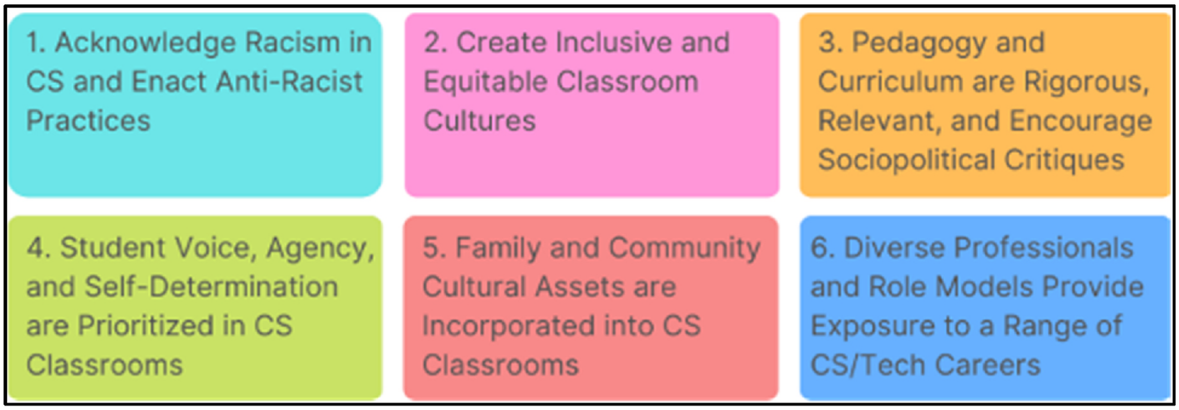

Fig. 1. The Kapor culturally responsive-sustaining computer science education framework.

co-designers of the learning activities and the research study (Famaye et al., 2024; Arastoopour Irgens, Adisa, et al., 2022). In each iteration, we first prioritized building relationships with children and staff and spent several weeks volunteering at the centers without engaging in data collection. We assisted children with their homework and brought robots and games to play with the children. This initial time spent with the children was designed to build rapport and engage in play between the youth and the researchers to build a foundation for trust and encourage participation in later activities (Cumbo et al., 2019). In the early design stages, we employed cooperative inquiry techniques (Yip et al., 2013) such as low-fidelity prototypes, storyboards, sketches, and other tangible objects. Children's roles included testers, informants, co-designers (Druin, 2002; Fischer et al., 2021). Over three design cycles, we modeled how children's roles shifted from designers of AI learning activities to designers of AI technologies. By allowing children to engage in learning and design at the same time, we were able to include children as co-designers of AI computing content knowledge and practices that they were not yet familiar with (Famaye et al., 2024). Researcher and child reflections on these early designs revealed that 1) children were more engaged in activities that provided a story-based narrative, 2) children were more engaged when allowed to create their own stories and build their own technologies, 3) children did not fully integrate a critical lens into their computing work likely because some activities included computational practices without a focus on sociopolitical issues, while other activities involved discussion of sociopolitical issues without integrating computational practices, 4) children were not invited to explore oppressive histories of marginalized populations, which is important for situating students' understanding of systemic oppression, and 5) we adopted existing programming tools that were not specifically designed for students to explore socio political issues in AI.

Building on this prior work (Arastoopour Irgens, Adisa, et al., 2022; Arastoopour Irgens, Vega, et al., 2022), we are developing a story-based digital role-playing game to further test our designs in elementary school classrooms in which each activity is grounded in a sociopolitical context. The goals of this particular study presented in this paper were to co-design and test an initial prototype of the digital game with children in order to determine 1) how the children interacted with the introductory level of the game and 2) which aspects of the game children enjoyed and which aspects they wanted to change. The insight gained from this study will allow for children's perspectives, ideas, and interests to be further implemented into the full design of the digital critical computational literacy game.

In initial co-ideation sessions, children in an after-school center met with researchers to review digital visuals and mockups of a game environment and add to the game. Children supported the idea of time traveling to a large city to explore how technologies have changed and could be harmful. We provided three opportunities for children to gather in groups and provide feedback on the game design and activities. First, we asked them to provide vocal feedback on the mockups, and then draw what they imagined game elements would look like and what their functionalities would be (Fig. 2). Second, we asked them to provide a name for the agency and choose their own agent names. Third, we asked them to draw and write about harmful versus helpful technologies. Children's ideas are summarized in Table 1.

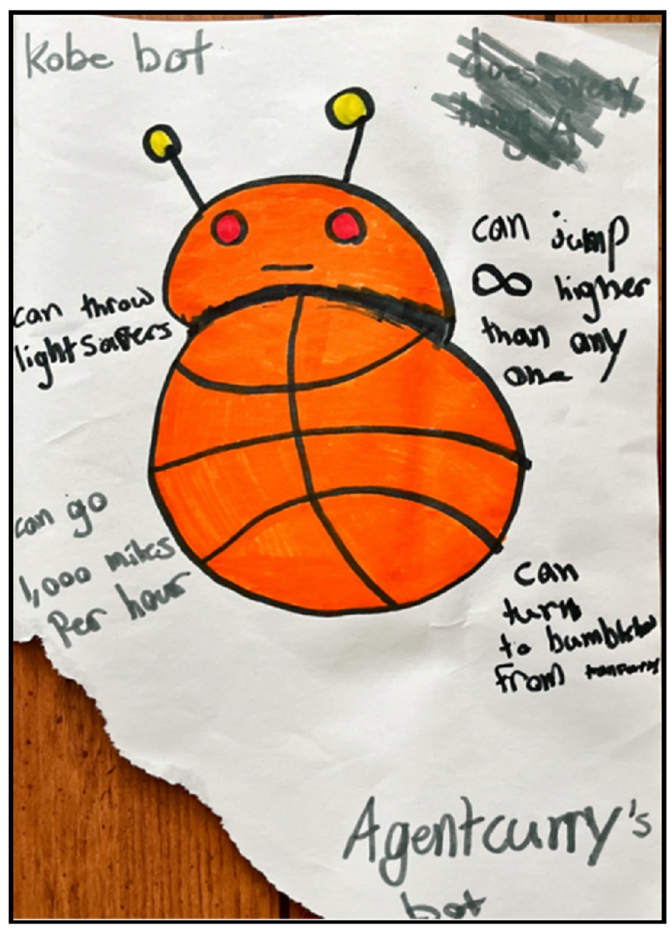

Fig. 2. One child's drawing during a co-ideation session with researchers of how they envisioned a main character for the game, Bot Buddy, that would travel with players to the future.

Table 1
Children's suggestions and ideas for the design of the digital, critical computing literacy game resulting from initial co-ideation sessions with researchers.

Design Aesthetics	Game Narrative	Game Objects
Characters should be animated	Future travel place should be a large city (e.g., Los Angeles, New York)	Customize and name characters
Soft music in the background	Agents can win tokens and buy things	Develop their own avatars
Characters should make fun of agents' out-of-style clothes	Agents can sell badges for coins	Customize a space of their own, such as an office, to display badges
	There should be a villain	

3.2. The design of SPOT: a role-playing digital game for culturally responsive computational thinking

The initial ideation sessions with children resulted in the researcher's further development of a game wherein children role-play as agents for a top-secret agency called S.P.O.T. which stands for Solving Problems of Tomorrow (Adisa et al., 2023). After players agree to volunteer as agents for a secret mission, one of the non-player game characters, Captain Storm, tasks them with traveling to the future to investigate machine learning technology-related problems and bring back the knowledge and skills they acquire to solve present day problems, such as bias in artificial intelligence technologies. Another character, Bot Buddy, travels with the player to provide help and guidance along the way.

The game consists of Levels 0 through 4. Players complete a series of activities to earn badges and power-ups that help them progress and advance as agents through the successive levels (Read & MacFarlane, 2006). Power-ups, which players get upon completion of each level, consist of gaining megajoules that act as fuel to bring players back to the present day after their mission. Badges, such as "Algorithm All Star" and "Machine Learning Master," are used to show the players their learning achievements and advancement in knowledge and are added to their agent profiles. The megajoule power-ups and achievement badges serve the purpose of delineating the different levels which increase in complexity as the player progresses (Klopfer et al). Each level builds upon the knowledge the children obtained in a previous level while they navigate through game-based lessons on machine learning, algorithmic bias, how algorithmic bias could affect children such as themselves, ways to mitigate such biases, and the historical oppression of marginalized populations regarding technology development and deployment.

This study focused on the pilot testing of Level 0, the introductory level in the game. Testing the first level would allow for the fine-tuning of any usability issues, gauge children's interest levels, and test data collection aspects of the game prior to completion of the other levels and deployment into classrooms. Level 0 introduces the mission to the players and guides them through S.P.O.T. agent training. Players are welcomed to S.P.O.T. by Captain Storm and introduced to Senior Agent Spark, a non-player character (Fig. 3), who then guides the player through the use of their virtual tablet through which they can create their secret agent profile, learn the system of badges and megajoules, and learn how to communicate with the agency through their virtual journal when they are in the future. Players are encouraged to choose an agent name based on their interests. For example, a player may choose to be called "Agent Frog" because of their interest in animals and nature. Players are introduced to the Senior Agent non-player characters and their profiles (Fig. 4) for inspiration when creating their own profiles.

Level 0 was also designed for collecting baseline data regarding children's machine learning knowledge and their perceived sense of sociopolitical control within their communities prior to engaging in the learning activities in other levels of the game. Questions are embedded throughout the level and include interactive questions such as *Draw a picture of what you think an algorithm is*. A five-point Likert scale, which was adapted from the Elementary CS Attitude Scale (E-CSA) and the Brief Sociopolitical Control Scale for Youth (BSPCS–Y) and uses a smiley-o-meter with images of progressive smile and frown faces (Famaye et al., 2024), is given to the youth toward the end of the level. For the adapted survey, the Flesch-Kincaid readability test calculated a fourth grade reading level and the Gunning Fog scored a 5.1, which indicated the survey was "easy to read."

3.3. Usability testing with children

We conducted usability and user experience testing with children on

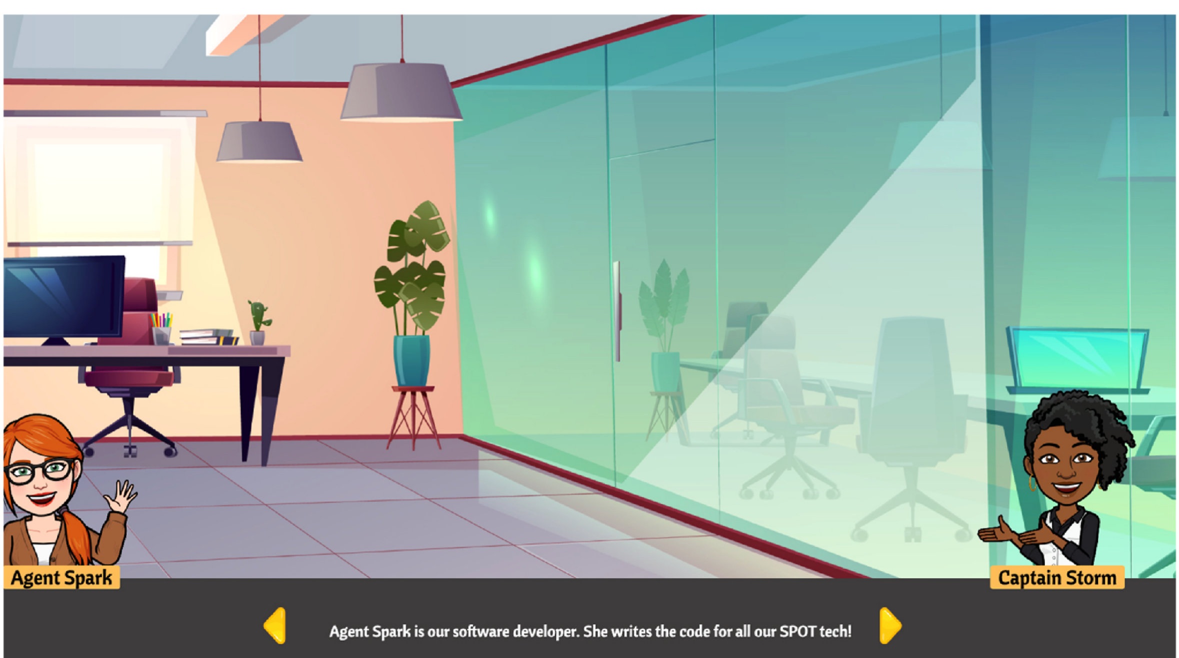

Fig. 3. Level 0 in the game in which children who are role-playing as agents, are welcomed to S.P.O.T. agency by non-player characters, Captain Storm and Senior Agent Spark.

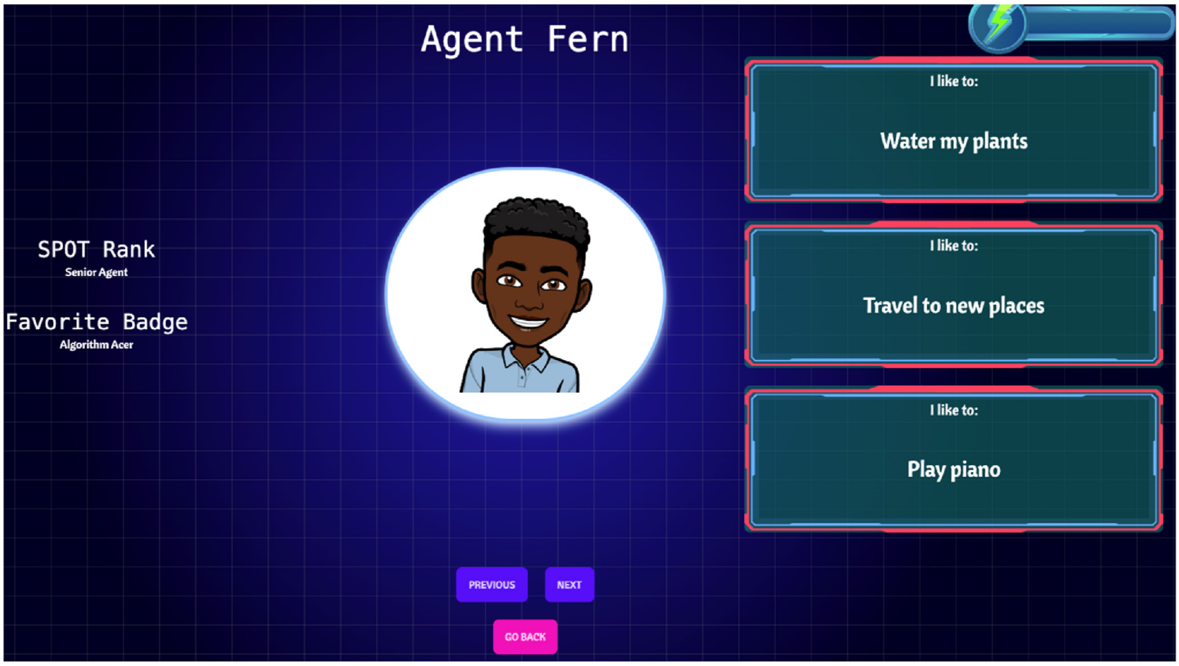

Fig. 4. The profile of one non-player character, Senior Agent Fern.

Level 0 of our game design, S.P.O.T. Usability is defined as “extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use” and user experiences is defined as “user’s perceptions and responses that result from the use and/or anticipated use of a system, product or service” (ISO 9241–11:2018(en)ISO 9241–11:2018(en)). Children are observed testing the game and attempting to complete specific tasks within the game. Through usability testing, in addition to determining if there were any errors or bugs within Level 0, we were also able to ascertain these children’s interests and values so that these perspectives could be implemented into future designs.

Research shows that 80% of usability problems can be detected with four or five subjects and additional subjects are less likely to reveal new information (Virzi, 1992). Thus, we recruited 7 children ranging from ages 7–12 (Table 2). Following White and colleagues’ suggestions (White et al., 2011), we conducted “vertical slice quality” testing in which one game level was fully developed and tested. Pseudonyms used are the agent names each child chose for themselves during the pilot testing.

Table 2
Child participants and demographic information.

Pseudonym	Age	Grade	Gender	Race/ Ethnicity	Schools and Special Programs
Agent Indy	7	2nd	Girl	Black/ African	Public
Agent Flash	8	3rd	Boy	Black/ African	Public
Agent A	8	3rd	Girl	White	Public
Agent Claw	10	5th	Boy	White	Public; Gifted and talented program; attention Deficit Hyperactivity Disorder
Agent Boeing	10	5th	Boy	White	Public; attention Deficit Hyperactivity Disorder
Agent Life	12	7th	Girl	Black/ African	Public
Agent Book	12	7th	Girl	White	Public

3.4. Data collection

3.4.1. Observations

Drawing on Moreno-Ger and colleagues’ suggestions (Moreno-et al., 2012), we created playscripts and engaged in screen casting of the test play sessions and recorded audio and video with minimal coaching from the researcher team. Research suggests user testing should be conducted with more than one evaluator (Kessner et al., 2001), and thus, three researchers observed, took observational notes, and recorded virtual live game play sessions by inviting child and parent participants to Zoom sessions. Each in-play session lasted 20–30 min. Parents were invited to observe and assist their child with technical issues along with the researchers. Sessions were video recorded and transcribed. Parental consent and child assent was collected before the recording of game play sessions.

3.4.2. Post-game interviews

We conducted semi-structured interviews on Zoom immediately after the game play sessions with parents present. Interview questions were inspired by observational notes and items from the Usability Metric for User Experience (Finstad, 2010) and the children’s adapted Usability Metric for User Experience (Putnam et al., 2020). All interviews were recorded on Zoom and transcribed. Parental consent and child assent was collected before the recorded interviews.

3.5. Data analysis

3.5.1. Qualitative coding

The transcribed game play recordings and interviews were combined into one data table. We, then, inductively coded the data through the lens of Moreno-Ger and colleagues’ (2012) Serious Game Usability Evaluator analytic framework (Moreno-et al., 2012) to derive qualitative codes focused on dimensions of user learning, user engagement, and user issues with the design. The goal was to identify evidence related to any “stumbling blocks” in the design that were present in the initial level of the learning game prior to the final design and implementation of the entire game (Moreno-et al., 2012), p. 2]. Three researchers first independently reviewed the qualitative data collected during the pilot study to include field notes, interview videos and transcripts, and game play videos and transcripts (Thornberg and Charmaz, 2014). Then, the researchers met to discuss the emerging themes within the discourse and observational data and reached an agreement on open coding (Kessner et al., 2001; Saldaña, 2011). The final coding scheme consisted of nine codes or themes that emerged related to user satisfaction, usability, and issues related to usability (Table 3): Learning; Satisfied/Excited; Frustrated/Negative; Confused; Skipping Question/Activity; UI Difficulty; Disappointment/Unmet Expectations; Responding to Characters; and Suggestions/Comments.

Table 3
Coding Scheme for user experience testing.

Code	Definition	Example	Cohen's Kappa on Samples
Learning	The user figures out how to perform an action that was unclear before (learn to play), or when the user is actively engaging in consuming content (learn content) or when they express they learned WHY a design choice is made	"I think Google is helpful because you can use the search engine to find information linked to helpful resources. Oh, I got it. Oh, I got it. I don't have to use a recording thing. I didn't look at that."	1.0
Satisfied/Excited	The user displays a remarkably positive reaction.	"I still volunteer! I still volunteer! I always wanted to see the future! I still volunteer!"	0.85
Frustrated/ Negative	The user voices or displays negative feelings at not being able to do something.	More questions. [heavy sigh] [frustrated expression]	0.94
Confused	The user expresses that they do not know how to perform an action, and/or does not know what he/she is supposed to do. But does not show evidence of a particular affect.	Let's see. I Think I know. Let's see. Okay. Yeah, I don't know how to spell it.	0.97
Skipping question or activity	The user does not answer questions or participate in the activity. The participant skips audio and goes to next screen quickly or proceeds without fully answering the question	[Chooses helpful for tablet but does not answer why, clicks next immediately]	1.0
UI difficulty	The user has trouble navigating the UI, or completing a task because of the UI design choices,	"It was probably the one where I was setting up my name and the text box wouldn't go away. I Was like, 'What's happening here?'"	0.90
Disappointment/ Unmet expectations	The user expresses disappointment or an expectation that was not met in a design choice/UI or activity. "I would have loved to see … " "I was hoping to see this … "	"I was hoping to see flying cars, planes, with instead of the color white, they were high-tech blue."	0.81
Responding to characters	The user responds to the characters directly in the game or discusses their opinion of the characters with researchers	"I focus on sitting there. Aw, these [agent profiles] look just like all of you!"	0.14, 1.0
Suggestion/ Comment	The user verbalizes a comment or a suggestion to improve the design of the game	"I'll say, I say cut it and have a little three slides or even four, but don't make too many slides. They just get bored of it faster."	0.97

Data were segmented into a spreadsheet where each row was a conversational turn of talk, and each column represented a code. If a code occurred, then a 1 was placed in the cell; if a code did not occur, then a 0 was placed in the cell. Two researchers coded a sample of 20% of the data that was purposefully selected by a third researcher such that the data would span all codes and that the sample was not sparse. Cohen's kappa was calculated between the two researchers, and kappas of greater than 0.81 were reached on each code except for Responding to Characters. The same two researchers discussed and revised the definition, resampled, and recoded to achieve a kappa of 1.0 on a second sample. The two researchers then split the discourse data and coded the remainder of the utterances individually.

3.5.2. *Epistemic network analysis*

After quantifying the coded data, we used the ENA webtool (Marquart et al., 2018) to measure and visualize how children connected across the codes when engaged in gameplay and when interviewed. ENA measures the connections between discourse elements, or codes, by quantifying the co-occurrence of those elements within a defined segmentation of discourse (Shaffer, 2018, p. 520). In this study, co-occurrences of codes were calculated if they occurred within a sliding window (Siebert-Evenstone et al., 2017) of four utterances. In a sliding window model, we measure co-occurrences of codes within 4 lines of utterances. The co-occurrences are counted only if they occur 1) within the fourth line itself or 2) between the fourth line and any of the three preceding lines. Then, the window slides down one line, and the process is repeated until the end of the dataset for that unit of analysis. This procedure prevents the duplication of co-occurrence counts. We chose a window for four and justified our choice quantitatively and qualitatively (Ruis et al., 2019). A window size of four optimized the variance in the data when compared to ENA models with window sizes between 1 through 10. Moreover, a qualitative review of the dataset indicated that children typically switched topics at or around four lines. A limitation of the ENA webtool is the inability to select variable sliding window sizes and thus, a window size of four was applied throughout the entire dataset. The units in this model were each child in each condition (game play or interview) for a total of 14 units. We segmented the interview and the observation as separate units of analysis because children discussed and experienced different topics during the two conditions. For each unit, ENA accumulates co-occurrences of codes within each sliding window and then represents these co-occurrences as a weighted node-link network in which the nodes are the codes and the links are co-occurrences. Heavier links indicate that the codes co-occurred often and lighter links indicate that the codes did not co-occur as often for that child in that condition.

Each network is also represented by an adjacency vector. ENA binds these vectors into a matrix in which each row represents one unit's adjacency vector. Then, a singular value decomposition is conducted on the matrix, and the nodes are placed in a fixed two-dimensional space. This dimensional reduction allows us to compare and measure networks in a fixed mathematical space: an x-y plot. In this plot, the networks can be viewed. However, ENA also calculates the centroid of each network and plots these points in this space. Viewing the centroids allows for an aggregate visualization of all units' networks as a point and allows for running additional statistical analysis on the centroids as single datapoints. For additional mathematical explanations see (Arastoopour Irgens et al., 2020; Bowman et al., 2021; Shaffer & Ruis, 2017). The analysis captured 28% of the variance in the x dimension and 23% in the y dimension. The Pearson goodness of fit was 0.99 in the x dimension and 0.97 in the y dimension.

To find similarities in children's experiences and comments, we employed a k-means clustering analysis in R Statistical Software (v4.3.2;

R Core Team 2021) on the ENA centroids. K-means clustering analysis is a mathematical tool used to generate groupings based on the minimum distance between the centroid and the closest mean for a predetermined number of groupings (Jain, 2010). K-means clustering has been used in prior studies to group ENA networks in post-hoc analyses (Arastoopour Irgens et al., 2019; Gašević et al., 2019). In this case, the ENA participant centroids were downloaded as coordinates in the two-dimensional space and uploaded into R. We calculated the total within-clusters sum of squares and plotted the values against the number of clusters to create a scree plot. We also calculated within-cluster distance for each observation and its distance to the nearest cluster, known as the silhouettes. We then plotted the average silhouettes for each cluster, k. Both the scree plot and the silhouette plot revealed that the optimum number of clusters for this dataset was three.

4. Findings

4.1. K-means clusters on ENA centroids

The k-means clustering analysis was optimized at three clusters (Fig. 5) using the scree and silhouette methods. The within cluster sum of squares by cluster was 3.16 1.94, and 1.0, and the total within was 6.11. The between sum of squares divided by the total sum of squares was 78.1%. The first cluster (6 data points) contains a mix of interview and observation data from Agent Life, Indy, A, Book, and Boeing. The discourse from this first cluster was mainly about excitement for the characters. The second cluster (4 data points) contains a mix of interview and observation data from Agent Claw, Indy, and Flash. The discourse from this second cluster was mainly about excitement and frustration about various aspects of game play. The third cluster (4 data points) contains only observation data from Agent Flash, Life, A, and Boeing. The discourse from this third cluster was mainly about confusion regarding the UI and content in the game. Each child's interview and observation data clustered into different groups except for Agent Claw (Group 2) and Agent Book (Group 1).

4.2. Group 1: excited about the characters

The network for the first cluster (Fig. 6) shows this group made the strongest connection between *responds to characters* and *satisfied/excited*. In these instances, children enthusiastically responded to the characters on the screen when playing the game. For example, at the start of the game, Captain Storm appears on screen and introduces the top-secret mission, Agent Indy had a big smile. When Captain Storm stated, "Are you ready to help us travel to the future?" Agent Indy said loudly to the screen, "I'm ready … I was born ready!" In another instance, when Spark a character in the game, asked the children, "Ever heard of algorithms?" four of the children responded audibly with "No" or "I don't think so." And to be humorous, the electricity malfunctions in one scene in the game and the screen slightly darkens. Spark says, "Gear did you overload the generator again?" One of the children exclaimed, "What happened?" responding to event.

When Agent Indy was introduced to the other characters whose agent names represented their interests, she responded in a positive

Fig. 5. K-Means cluster plot for 3 clusters. Points represent each child's network centroid in the plotted ENA space. Squares represent the mean point of the centroids for each cluster.

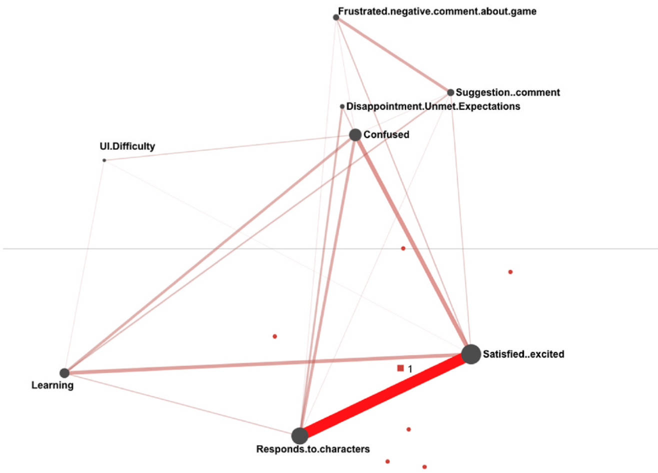

Fig. 6. The mean epistemic network for group 1. The circle dots represent the centroids of all participants in this group and the square represents the mean centroid.

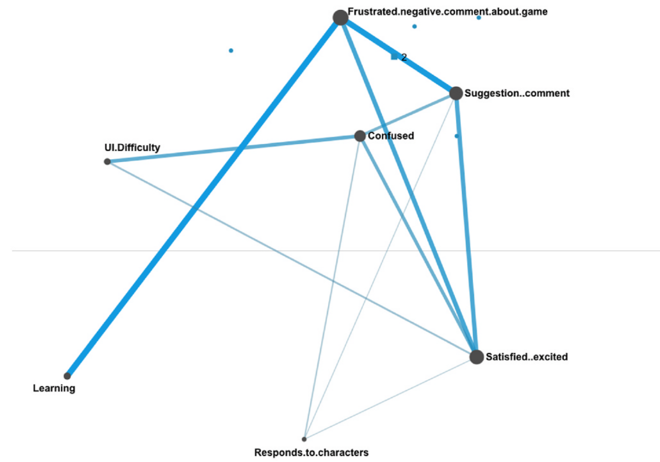

Fig. 7. The mean epistemic network for group 2. The circle dots represent the centroids of all participants in this group and the square represents the mean centroid.

manner. When Agent Gear was on the screen, Agent Indy stated, "Gear, gear up for motorcycle. Yeah, this is actually inspiring." When asked to create her profile and decide on an agent name, she considered several options based on her interests. She said out loud, "I like my gadgets. I am kind of like Agent Sparks … Okay, so electronics and building robots …" She considered selecting her name as Agent Cyborg and then considered Agent Ninja because of her interest in ninjas. But then she exclaimed that those choices were "tacky." Ultimately, she settled on Agent Indy because of her experience programming with the Sphero Indi robot. She stated, "That's the robot I worked with. It's cool, they're really cute. I like Indies … Indy. That's going to be easy for me [to spell and remember]." The other agents also selected secret agent names that aligned with their interests and considered different options.

During his interview, Agent Boeing also noticed the pairing of the characters names with their interests. When asked "What do you think about the characters?" he stated, "They're really good names. The name I like the most was Agent Spark. It's a really clever name. It can match so many stuff. It can match a game console, a car, a plane, lots of different things." Agent A also noted that the characters were "funny and cute," and that her favorite character was Captain Storm.

Agent Life noticed that the characters looked like the researchers and stated, "The characters look fun … I like the way that they kind of look like you guys. You guys customized it to look like you guys. I like that you guys have your voices in it. I like the accent." Here, Agent Life expressed excitement that Captain Storm had a Nigerian accent, which aligned with Agent Life's Nigerian ethnicity and family heritage.

This group also made connections with *Disappointment/Unmet Expectation*. Although this was not a strong connection in their mean network, this was the only group who made connections with this code. These comments were exclusively related to expectation around time travel. For example, in her interview, Agent A stated, "I was expecting to see the time machine." Agent Boeing stated, "I was hoping to see flying cars, planes, with instead of the color white, they were high-tech blue."

4.3. Group 2: excited but also Frustrated about the content

The network for the second cluster (Fig. 7) shows this group made the strongest connections between *Learning* and *Frustrated/Negative*, *Suggestions/Comments* and *Frustrated/Negative*, and *Satisfied/Excited* and *Frustrated/Negative*. In these instances, children expressed both their likes and dislikes with the game while they were learning how to navigate the game.

In his interview, Agent Flash was asked "Do you get what was happening the story so far?" He responded, "Yeah, I understand what was happening. I understand what you have to do … but there's no way to get to your SPOT tablet … so at first I was like, this looks so advanced and everything and I was actually surprised and I didn't expect it to look like this." Here, Agent Flash explained that he was impressed with the look of the game and that he understood the mission. However, he also noted some frustration with accessing important components of the UI, such as the SPOT tablet.

Similarly, Agent Indy highlighted likes and dislikes together, noting that "I have a concern. You'll get bored … cut up the talking. You're talking too much. Kids, when they hear talking a lot and a lot, they'll be like, can you stop talking?. the exciting part was when you travel." Agent Indy, like many of the other children, was excited about the time traveling narrative. However, she expressed frustration at the amount of text and audio without intermittent activity. She suggested that the game could be redesigned to limit or "cut up the talking."

Agent Claw had a similar sentiment in his interview when he stated, "They [the characters] were giving unnecessary information. I kind of just ignored that part. I mean, I think that you should still include *some* of that because–So, it would be instead of just a dictionary tell you exactly it, it could be like you could have some story to it." Here, Agent Claw felt that the characters were providing excess information that was "unnecessary," and he likened the information presented to that of a "dictionary." As a result, he did not attend to some of the information in the game. Like Agent Indy, he suggested that the game could be redesigned to reduce the text and audio content and have more "story to it," suggesting that the narrative could be more cohesive in the game.

4.4. Group 3: confused about UI and content

The network for the third cluster showed this group made the strongest connections between *Learning* and *Confused,* and *UI Difficulty* and *Confused*. In these instances, children enthusiastically expressed confusion about navigating the SPOT tools in the game. For example, when asked to report about harmful versus helpful technologies, some children could not identify the technology that was presented. When viewing a WiFi icon, Agent Life pointed and stated, "I am not sure what this is." Similar Agent Flash was confused about a social media icon and asked, "What's this technology?" Other children had difficulty using the camera to capture their paper drawings, and some could not locate the power button on the SPOT tablet. All children used the speech to text option with no difficulty (Fig. 8).

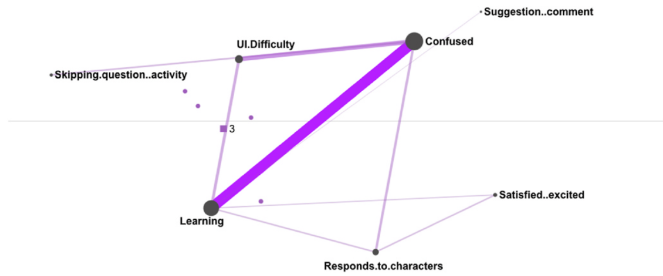

Fig. 8. The mean epistemic network for group 3. The circle dots represent the centroids of all participants in this group and the square represents the mean centroid.

5. Discussion

Findings in this user experience study suggested that children expressed excitement about the characters and narrative in the game but also had frustrations regarding the UI design, tools, and amount of information provided through audio and text. In terms of design ideas, children suggested reducing/segmenting the text or options for turning off audio, adding visual elements of time travel, and providing opportunities for more interactivity. These changes have and will be implemented in future design and testing cycles. For example, we have added an interactive, clickable time machine for children to being their mission (Fig. 9).

5.1. Children as critical testers and co-designers of computational learning activities

The children's excitement for the time travel mission and the style of characters aligns with children's design ideas from our prior studies. This round of co-designing and testing with children provides more evidence for game-based learning as a potentially fruitful avenue for engaging elementary school children in computational thinking. Although in this user experience testing study children did not go beyond level 0 to experience the sociopolitical computational thinking activities, the results supported the choice of characters, narrative structure, and tools that are the foundation for further activity and engagement in computational thinking for future iterations.

Children shifted between the role of tester and co-designer, which allowed researchers to collect meaningful data about their user experience to inform improvements in the design of the game. Testing with children using a "vertical slice quality" (White et al., 2011) approach allows researchers to closely mimic how the game will actually be implemented but focuses on one level of the game. Pairing live game testing with interviews developed from the children's usability survey (Putnam et al., 2020) revealed insights into how children play the game as testers as well as their ideas for improvement of the game. This combined approach also allows researchers to go beyond measuring reading level appropriateness and other independent measurements to gather detailed information directly from children's action and discourse on how much text shown be shown on each page, how to introduce characters, and how to adjust for interactivity. For example, we noted that all children easily employed the drag-and-drop functions and used the speech to text option to input responses into their journals and some chose to edit the text using the keyboard after recording their responses. Uniquely, Agent Book showed enthusiasm when using the drawing tool, and Agent A chose to use the function that allowed agents to draw using paper and use the computer camera to take a photo of the drawing and upload the physical photo (although she had some technical difficulties which we will fix in the next iteration). This suggests the importance of designing and testing multiple forms of digital expression (Cunningham & Murphy, 2018) in game-based learning to broaden participation in computing spaces.

These findings support that children are valuable testers and co-designers for game-based learning environments. Our approach aligns with others in the Child-Computer Interaction field who design experiences for children to embody multiple, flexible roles as testers and co-designers of both computational tools and the learning activities (Jones & Bubb, 2021; Famaye et al., 2024). In addition to providing children with flexible roles, adult researchers are needed during testing and design sessions to provide support and encourage children to explore and experiment with technology or learning activities (Frauenberger et al., 2011; Guha et al., 2005). This approach with children is different from other user testing literature that suggests researcher intervention should be minimal (Druin, 2002). Researcher interactions with children during user testing allows designers to understand children's preferences to better meet their needs and interests.

5.2. Narratives, play, and characters with intersectional identities

The aspects of the game that both excited children and elicited the most feedback was around the playful futuristic narrative and the design of the characters. The characters in the game were purposefully developed to make marginalized intersectional identities more visible and provide counternarratives (Gray, 2020; Rankin & Thomas, 2020) to traditional images of those who engage in computing. Findings suggest that girls responded positively to these choices. Agent Life specifically expressed her enthusiasm with Captain Storm, a Black woman in a leadership role with a Nigerian accent, because she could see herself and her families' heritage in the character. Agent A, a White girl, also noted that Captain Storm was her favorite. Other children responded well to the diverse presentations of Agent profiles and interests, finding the profiles "inspiring." All children chose secret Agent names that aligned with their own varied interests when creating their own profiles. This initial Level 0 testing of S.P.O.T. was grounded in several components of Kapor's culturally responsive and sustaining computer science education framework (Kapor Center, 2021), such as incorporating family and community cultural assets, exposure to diverse professionals/role models to a range of technology careers, and prioritizing student voice. This game honors and affirms students' intersecting identities and the findings reveal students' positive responses to a range of people in computing.

The game also provides space for students to explore their own interests and identities in relation to computer science environments. For example, Agent Indy responded vocally to the narrative story around the multiple characters in the game. She noticed that the names of the non-player character agents aligned with the characters' multiple interests

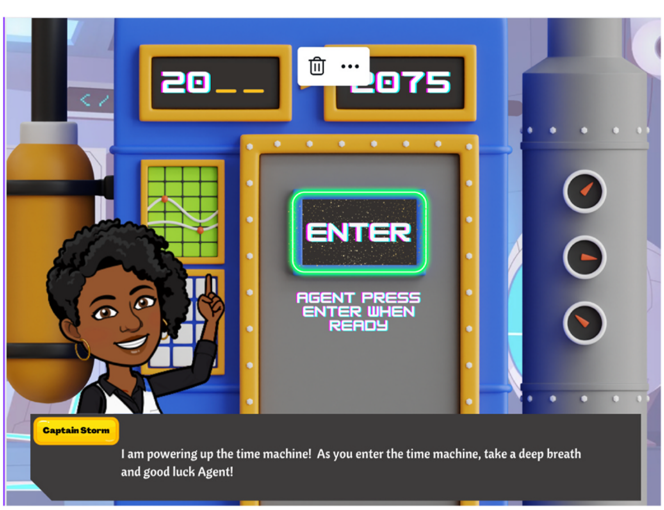

Fig. 9. Added interactive time machine for children to being their missions based on feedback from children in their interviews.

and identities in computing and technology domains, which she claimed was "inspiring." The stories of the non-player characters and the freedom to choose an agent name allowed Agent Indy to freely reflect on the intersection of her intersectional identities and interests with relation to technology. She considered Agent Cyborg but ultimately decided on Agent Indy because the game provided her with an opportunity to reflect on a prior experience with Sphero Indi robots and to integrate her prior experience with her agent identity in the game. Such opportunities in games allow players to develop *projective identities*, virtual characters that players develop and project their values and desire upon while also viewing the character as an aspirational identity (Gee, 2003). Games in which children create and play as virtual characters with self-determined names and attributes allow children to project aspects of their identities onto characters in domains that they have not yet explored, such as computing. At the same time, children can also tinker with aspects of their identities, given the constraints of the game, and experiment with who they want to be. In our case, children could see and reimagine themselves as secret agents who engage in computing practices in ways that they care about and ways that they are learning about.

Thus, the findings in this study support efforts to broaden participation in computing in ways that go beyond providing access to existing tools, but rather, create spaces for marginalized elementary school-aged children to participate in computing in ways that are meaningful for them and make their cultures more visible in computing education environments (Margolis et al., 2012; Rich et al., 2019). Future testing will explore the remainder of the components in the culturally responsive and sustaining framework including students exploring bias and harm in computing.

6. Conclusion

As the world becomes increasingly digitally reliant, it is important for all students to develop new computational literacies. To broaden participation in computing and reach children who have been historically excluded from computer science, researchers and educators can rely on culturally sustaining pedagogies that honor children's intersectional identities and diverse ways of knowing and being. Co-designing game-based learning environments with children through these lenses have the potential to engage and encourage all children to develop computational literacies in ways that allow them to participate in a highly digital society while also shaping future participation in ways that are meaningful for them.

CRediT authorship contribution statement

Golnaz Arastoopour Irgens: Writing – original draft, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Cinamon Bailey:** Writing – review & editing, Resources, Formal analysis, Data curation, Conceptualization. **Tolulope Famaye:** Formal analysis, Data curation, Conceptualization. **Atefeh Behboudi:** Writing – review & editing, Resources, Data curation.

Selection and participation

All children in this study were recruited through their parents. The study took place at their homes and through the use of virtual meeting technology. All parents were present with their child during user testing. Parents and children were told this was a game that we are designing and testing together. Data related to the study were collected after approval from the Institutional Review Board at [removed for anonymous review], following all the regulations and recommendations for research with children. Researchers obtained written consent from the parents/guardians of all child participants permitting the data collection. Children were informed about the data collection process and their participation in the study was completely voluntary. In addition, children were able to withdraw their consent for the data collection at any time without affecting their participation in the activity.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data that has been used is confidential.

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