S.P.O.T: A Game-Based Application for Fostering Critical Machine Learning Literacy Among Children

Ibrahim Adisa
Learning Sciences, Clemson University, Clemson, United States
iadisa@g.clemson.edu

Ian Thompson
Learning Sciences, Clemson University, Clemson, United States
icthomp@g.clemson.edu

Tolulope Famaye
Learning Sciences, Clemson University, Clemson, United States
tfamaye@g.clemson.edu

Deepika Sistla
Learning Sciences, Clemson University, Clemson, United States
dsistla@g.clemson.edu

Cinamon Sunrise Bailey
Learning Sciences, Clemson University, Clemson, United States
cinamob@g.clemson.edu

Katherine Mulholland
Learning Sciences, Clemson University, Clemson, United States
krfreem@g.clemson.edu

Alison Fecher
Learning Sciences, Clemson University, Clemson, United States
afecher@g.clemson.edu

Caitlin Lancaster
Learning Sciences, Clemson University, Clemson, United States
cma8@g.clemson.edu

Golnaz Arastoopour Irgens
Learning Sciences, Clemson University, Clemson, United States
garasto@g.clemson.edu

ABSTRACT

This paper describes S.P.O.T., a game-based application for promoting children's practical understanding of ML concepts and applications. Current tools for teaching ML in K-12 engage students in playful exploration of ML mechanisms and teach ML from a cognitive perspective. However, in S.P.O.T, learners interact with ML within real-life sociopolitical contexts and examine how ML predictions impact their daily lives and communities. Through the immersion of stories that mirror children's lived experiences, S.P.O.T. provides elementary school aged children with opportunities to learn how machine learning applications function and develop children's abilities to critically examine, question, and reimagine the consequences of ML decisions in the real world.

CCS CONCEPTS

• **Human-centered computing**; • **Collaborative and social computing systems and tools**;

KEYWORDS

Machine Learning, AI, Elementary School, Game-Based Learning, Critical Pedagogies

ACM Reference Format:
Ibrahim Adisa, Ian Thompson, Tolulope Famaye, Deepika Sistla, Cinamon Sunrise Bailey, Katherine Mulholland, Alison Fecher, Caitlin Lancaster, and Golnaz Arastoopour Irgens. 2023. S.P.O.T: A Game-Based Application for Fostering Critical Machine Learning Literacy Among Children. In *Interaction Design and Children (IDC '23), June 19–23, 2023, Chicago, IL, USA.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3585088.3593884

IDC '23, June 19–23, 2023, Chicago, IL, USA

ACM ISBN 979-8-4007-0131-3/23/06.
https://doi.org/10.1145/3585088.3593884

1 INTRODUCTION

An understanding of machine learning (ML) is important for productive engagement with modern technologies. However, the development of ML literacy at the elementary school level remains a challenge due to the opaque nature of ML systems and the limited opportunities for engagement with children [1, 2]. Tools such as Google's Teachable machine, Google QuickDraw, DancewithAI, and Cozmo robots promote understandings of ML. However, they do not engage children in the *critical* examination of ML systems. Without critical ML and AI education, elementary school students will not be prepared to face the increasingly discriminatory effects [3, 4] of algorithmic decision-making. In our work, we conceptualize *critical machine learning education* as computing education that centers social, ethical, and political orientations in students' learning of ML and AI [5]. This pedagogical approach is grounded in Freire's critical pedagogy [6] and influenced by constructionist design principles [7, 8]. This work-in-progress paper describes our design and development of S.P.O.T, an interactive story-based game, to facilitate upper elementary and middle school students' understanding of ML concepts and practices within a sociopolitical context.

2 RELATED WORKS

2.1 ML Education for Children

ML education at the K-12 level is still developing, and research in this area is varied [1]. Many newly developed ML curricula and learning environments involve the simplification of ML concepts in ways that are developmentally appropriate for children and allow for the exploration of ML within playful contexts. For example, in MIT's Scratch online learning environment [9], young users between the ages of 8 to 16 years have the opportunity to interact and learn about ML by integrating block-based codes with text classifiers and Google's Teachable machine models within the Scratch Application. There are also growing curricular resources like MIT's "How to train your robot" [10] that promotes ML skills among 9 - 14-year-old children by integrating physical activity with age-appropriate ML concepts. On the other hand, tools like MIT's App Inventor [11] and Google's Teachable machine (https://teachablemachine.withgoogle.com/) provide multiple opportunities for children to develop a more conceptual understanding of ML by collecting data to train models and using these models to create AI applications. Innovations like these change children's roles from consumers to producers of AI-driven content. These works mainly focuses on how children can utilize ML and develop an awareness of its sociotechnical nature, but little attention is given to how children develop the capability to critically use and examine the implications of ML designs and deployment. As part of our research on critical ML literacy among young learners [12], we have engaged middle school learners in afterschool programs in different ML technology-related activities aimed at facilitating their critical engagement with ML and AI. Based on the data we have collected and our experiences designing ML activities with children, we are developing a narrative-based application for engaging elementary school-aged children in critical ML activities within formal classroom environments.

2.2 Game-based Learning and Designs

Games are an integral part of our social and cultural environments [13]. They offer a constructive and creative way to facilitate learning and engage children in playful activities [13]. Game-based learning incorporates game elements in an organized learning context and narrative [14]. When designing educational or serious games for children, designers need to fit the game to users' level of experience and scaffold the learning experience through dynamic stories and pleasant challenges [15]. Within an effective educational game environment, students work toward specific goals as they take actions, make choices, and experience the consequences of their actions or choices [16]. Students also have the freedom to make mistakes and can learn through experimentation [17]. However, designing effective educational games capable of impacting learners' behavior and their perspective on societal issues requires an understanding of the need, interests, and skills of the learners [25]. In their review of educational game designs for children, Valenza and colleagues [14] identified 40 guidelines designers need to follow to develop games children find engaging and immersive. Some of these guidelines include having clearly defined goals, designing for teacher control, relating interface and narrative metaphor to children's world, using rewards like points and leaderboards, and using rich and colorful layouts. Miller and Kocurek [17] also advocated for the use of age-appropriate content driven by learning sciences principles and to establish a balance between play and learning opportunities. Educational games have been found to improve learning outcomes by virtue of their engaging and immersive nature [13]. Games can also be a creative avenue for self-expression and for telling counter-narratives that expose children to diverse perspectives and social justice [18]. Thus, through gameplay and immersion, students actively construct their own understanding of the world and gain mastery of the learning content.

2.3 Interactive Storytelling for Children

Throughout history, storytelling has been used as a tool for the transmission and dissemination of knowledge and values due to its natural yet powerful ability to communicate and position knowledge within familiar contexts and experiences [19]. Advances in computing and technology have, however, opened new possibilities for storytelling techniques. Interactive digital stories enhance the educational benefits of traditional storytelling by using interactivity and multimedia to develop engaging, challenging, and dynamic narratives [20]. Quality interactive stories are often characterized by (1) dynamic short stories, (2) appealing characters and multimedia that convey emotions, and (3) features that motivate users to solve the narrative paradox [21]. Successful interactive stories meet the social and emotional needs of the users by using elements that make the user feel more connected to the narrative [22]. As students interact with the stories, they may identify with the characters in the application, connect with the narrative, and even influence the flow of the story based on the choices they make in the application [23]. Consequently, interactive stories can emphasize the expression of multiple identities and perspectives and promote critical thinking by serving as a vehicle for telling counter-narratives and exposing children to perspectives that differ from dominant ones which sometimes promote oppression and inequalities [24]. Interactive digital storytelling can also be a powerful model for creating constructionist learning environments like educational or serious games [21]. This integration of interactive virtual and computational environments into interactive stories provides children with opportunities to create new experiences and tell their own stories within the application.

3 S.P.O.T. DESIGN

3.1 The Game-Based Interactive Design

S.P.O.T. is a hybrid physical/digital role-playing game in which students role-play as agents-in-training for a top-secret agency called Solving Problems Of Tomorrow (S.P.O.T). In the game, children play the role of the protagonist as they work as secret agents for the S.P.O.T. agency. They undertake the task of traveling into the future to investigate and solve technology-related problems that they encounter and then bring back the knowledge and skills they acquire to solve present problems. To sign up for their mission, children receive signup instructions from their classroom teacher, who role-plays as a senior S.P.O.T agent providing the child agent with the resources they will need as they proceed to login and signup as a young S.P.O.T agent.

The game experience is divided into progressive levels, and child agents must complete a series of activities to earn badges and power-ups that take them to the next level. Level 0 is the initial sign-up and training (Figure 1). At this level, the child is welcomed into the agency by the director, Captain Storm, who tells the child agent that the agency's scientists and researchers have developed time travel technology and are seeking agents for a top-secret mission. The top-secret mission is to time travel 30 years into the future, to investigate and solve technology-related problems that they encounter and then bring back the knowledge and skills acquired to solve present problems. The child agent is then introduced to other S.P.O.T. agents and undergoes a series of training on helpful and harmful technologies and the use of algorithms and ML technologies. The purpose of this training is to develop the agent's understanding of the social impact of technology and how machine

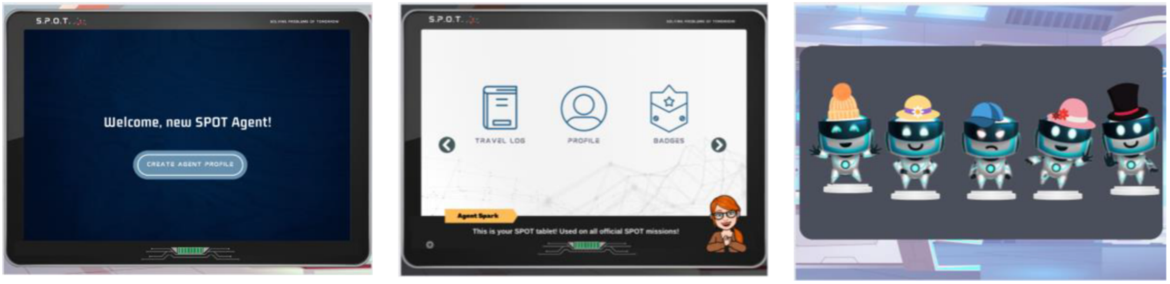

Figure 1: Scenes from Level 0 showing a) the new agent signup page, b) the tablet tools interface and b) bot buddy customization.

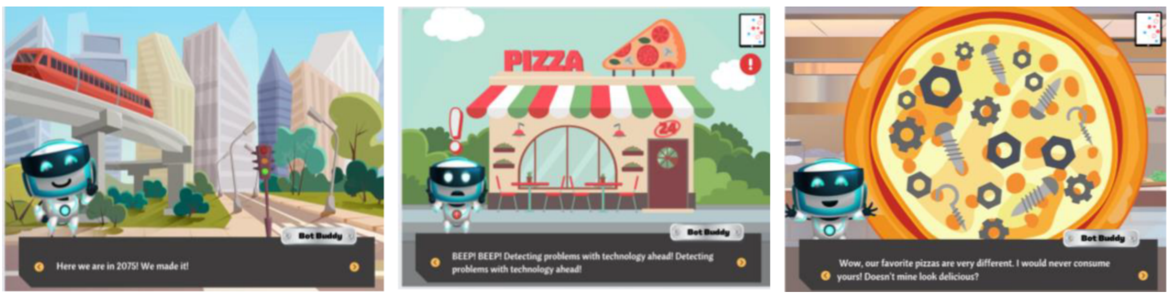

Figure 2: Scenes from level 1 showing a) agent and bot buddy in the future, b) the pizzeria and c) bot buddy, pizza output.

learning works. As part of the training in level 0, the agent receives a virtual S.P.O.T. tablet which is used to set up their agent profile and is loaded with tools that enable the child agent to communicate with the agency and access information that will be helpful on the journey. Two important tools accessible on the S.P.O.T. tablet are the *travel journal* and the *megajoules meter*. The megajoules meter shows a reading of the power usage on the time travel machine, which is powered by megajoules. To embark on their journey, children are given a head start of 100 megajoules, which is just enough to get them to the year 2075. However, they must earn more megajoules in the future by completing activities in order to return to the present world. The megajoules also serve the purpose of a reward mechanism that motivates students to complete more challenges in the game. The travel journal on the S.P.O.T. tablet allows users to provide audio narrations, text entries, or sketches to document their completed activities. Level 0 is completed when the child agent and bot buddy journey out of the present and into the future.

In Level 1, the child agent and bot buddy arrive in the future in a city, stopping for a snack at a pizzeria entirely operated by AI robots (Figure 2). The agent interacts with if-then algorithms and is introduced to the idea of embedded opinions in algorithms. In this level, the child agent revisits the concepts of algorithms which was introduced during the training in Level 0 and use their understanding of algorithms to make their favorite pizza in a drag-and-drop activity. Upon completing this activity, the agent receives an *Algorithm as Opinions* badge and unlocks Level 2. In Level 2, the bot buddy receives a message signaling problems with technology somewhere in the city. Upon visiting the location, the child agent and their bot buddy discover that the primary mode of transportation are self-driving vehicles that are accessed through facial recognition. However, they soon realized that most children are having trouble accessing the cars because the facial recognition technology does not consistently recognize children's faces. To solve this problem, the duo head to the factory of the manufacturers of the AI cars. When they arrive at the factory, bot buddy plugs into the computer system for a tour of the factory to learn about the car company's algorithm and how the cars are trained with facial recognition technology (Figure 3). Using an embedded Google Teachable Machine API revision, the child explores ML algorithms, testing datasets, and training datasets. As they explore the training data of the car company, they discover the dataset is biased against children and does not include photos of children in sufficient quantity or variety. Bot buddy then guides the child agent to develop a fairer dataset and re-train the algorithm. During this time, they also learn about the history of oppression against children and the harmful consequences of not including children in the design of technologies. Once the assigned activities are completed and the agent makes the required entry in the travel journal, they receive two badges symbolizing their understanding of machine learning concepts and bias. At the end of Level 2, the agent would have received sufficient megajoules to power the time machine and return to the present day. This unlocks the final level. In the final level, agents have returned to the present and are tasked with a final mission of helping their community. The agency requires them to apply their knowledge of ML and bias mitigation to build a social robot that helps people. They must consider problems existing in their communities and think of ways to solve these problems while minimizing bias as much as possible. They present these identified problems and solutions to S.P.O.T. scientists and engineers for future use and reference. Once this final mission is complete, child agents receive the *advanced special agent* badge.

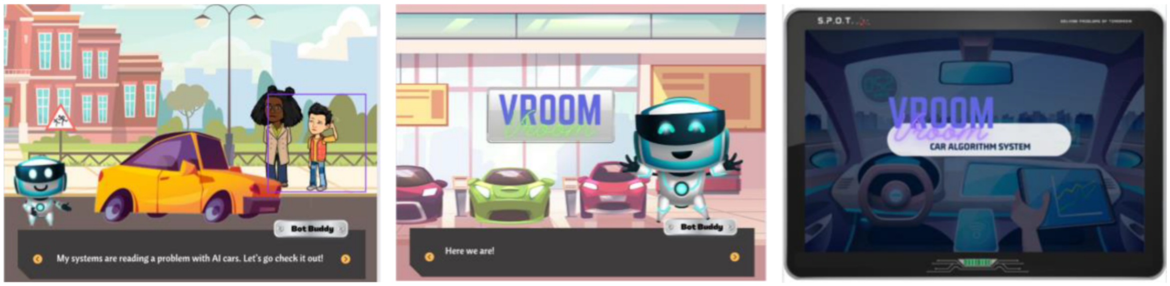

Figure 3: Scenes from Level 2 showing a) game characters with bot buddy and the AI car, b) the AI car company manufacturing plant and c) the AI car company training algorithm interface.

3.2 Technical Description

Our initial prototype is browser-based, and children can access the game using an internet-connected device. The front end of the application was developed using Svelte, an open-source JavaScript framework (Vercel Inc.). Svelte is a reactive, component-based framework that allows document object model (DOM) elements to be modularized, thereby streamlining development and reusability. The S.P.O.T user interface is divided into scenes, where each scene is associated with a Svelte component that is displayed dynamically as the user progresses through the application. The SvelteKit library handles server-side rendering and routing. To stylize DOM elements, we used the open-source CSS framework Tailwind CSS (https://tailwindcss.com). Tailwind CSS allows for a comprehensive assortment of utility classes for developing reactive components and applying consistent style across components. Additionally, the usage of utility classes works seamlessly with the component-based nature of the Svelte framework. We are using Node JS for the backend framework of S.P.O.T. and while MongoDB was chosen as an appropriate database. In the NodeJS server, we use Express Framework for Rest API and Mongoose to connect with MongoDB. We are also using Jsonwebtoken for authentication purposes and Bcryptjs for password encryption and decryption. We chose MongoDB because of its ability to easily store multiple data forms in document or JavaScript Object Notation (JSON) format. Within the S.P.O.T application, we intend to collect data related to (1) users' moves and logs including timestamps of when they log in and out of the game, (2) users' entries in their travel journal, (3) the choices users make to customize their badges, Buddy Bot, and travel pods, (4) dump files showing the block codes users executed and the processes they followed when they program their robots, and (5) snapshot of classifiers created by users as they investigate and solve challenges in the application. Since MongoDB is schemeless, we are able to easily store and retrieve these wide variety of data. Within the S.P.O.T. game, children will be using two applications embedded within the game: a modified Scratch interface and a modified Google Teachable Machine interface. First, we adapted the Scratch environment (https://playground.raise.mit.edu/httyr/), by reducing the number of blocks and options to focus children on the AI tasks using a webcam. (Figure 4). Our development team developed a Scratch extension that connects via Bluetooth to a physical TPBot Robot and includes blocks for programming robot functions. The TPBot is affordable, uses a micro:bit, is compatible with Lego pieces for additional construction, and has a child-friendly, blue-plastic-covered design. In addition, the TPBot robot responds to ML applications such as MIT's Text Classification blocks and Google's Teachable Machine. Second, we have also modified Google Teachable Machine to reduce options and focus children on AI tasks. Both the modified Scratch and GTM applications will be connected to the database, and all student moves will be collected in the database for future analysis.

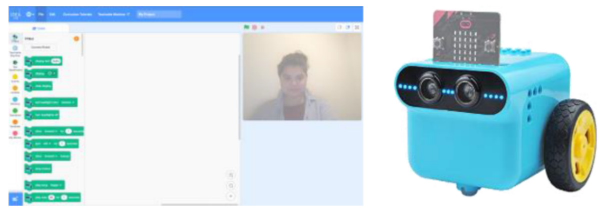

Figure 4: a) Adapted version of Scratch tool that will be embedded into the game and b) TPBot

4 FUTURE WORK

Our initial user testing of the S.P.O.T. application in our lab with graduate and undergraduate students and one elementary school-aged child provided useful insights for improving the user experience and designing the game to cater to the interest of students. We reduced the amount of text that users will read and made provisions for including voiceovers that increase the accessibility of the environment. Additionally, we modified several parts of the narrative to address identified gaps in the story. For example, new scenes and characters were added to engage users in conversations and provide opportunities for transitions between varying social contexts. Extra dialogue between the child agent and bot buddy was added so that users could learn more ML concepts. The agent bot buddy displays emotions at different points in the story, thereby providing opportunities for emotional connection with the child [22]. Future design and development of S.P.O.T will be completed in three design-based participatory research cycles. In Design Cycle 1 (Year 1), we will continue development of the graphics, user interface, front-end design, back-end, and database as described above. After a minimal viable product is developed, we will hold participatory design sessions with fourth- and fifth-grade teachers.

We will focus our sessions on discussing how to improve the game to include topics of interest to their students, determining what additional supports need to be incorporated into the game, and conceptualizing the role of the teacher in the classroom. In Design Cycle 2 (Year 2), we will conduct participatory design sessions and pilot testing at after-school centers. The game will be presented to children, and they will be asked to provide feedback by discussing, writing, or drawing their ideas. After redesigns, we will return to the after-school centers to conduct pilot testing. In Design Cycle 3 (Year 3), we will prepare summer training session for the early adopter teachers, sharing with them the results of the pilot study. The teachers and the research team will co-design personalized lesson plans and supplemental materials for each teacher and collect data during implementations.

5 CONCLUSION

In this paper, we discuss the initial design and development stages of S.P.O.T., a hybrid physical/digital role-playing game for fostering young children's critical understanding of AI and ML. This new project builds on our prior work engaging children in critical machine learning activities and learning [5] by engaging students in a holistic narrative-driven experience. By combining game-based design elements [14], digital storytelling [21], and critical constructionism frameworks [17], S.P.O.T. provides elementary school children with opportunities to critically examine, question, and reimagine the real-world consequences of ML decisions on marginalized populations.

ACKNOWLEDGMENTS

This work is funded in part by the National Science Foundation (ECR-2024965, DRL-2031175) and the Office of the Associate Dean for Research in the College of Education at Clemson University. The opinions, findings, and conclusions do not reflect the views of the funding agencies, cooperating institutions, or other individuals.

REFERENCES

[1] Gilad Shamir and Ilya Levin. 2022. Teaching machine learning in elementary school. *International Journal of Child-Computer Interaction* 31, (March 2022), 100415. doi:https://doi.org/10.1016/j.ijcci.2021.100415

[2] Henriikka Vartiainen, Tapani Toivonen, Ilkka Jormanainen, Juho Kahila, Matti Tedre, and Teemu Valtonen. 2020. Learning machine learning with very young children: Who is teaching whom?. *International Journal of Child-Computer Interaction*, 25, 100182. https://doi.org/ 10.1016/j.ijcci.2020.100182

[3] Safiya Umoja Noble. 2018. Algorithms of Oppression: How Search Engines Reinforce Racism (1 edition). NYU Press.

[4] Cathy O'Neil. 2016. Weapons of Math Destruction: How Big Data Increases Inequality and Threatens Democracy (1 edition). Crown.

[5] Golnaz Arastoopour Irgens, Hazel Vega, Ibrahim Adisa, and Cinamon Bailey. 2022. Characterizing children's conceptual knowledge and computational practices in a critical machine learning educational program. *International Journal of Child-Computer Interaction* 34, (December 2022), 100541. https://doi.org/10.1016/j.ijcci.2022.100541

[6] Paulo Freire. 1971. *Pedagogy of the oppressed.* Herder and Herder, New York.

[7] Seymour Papert and Idit Harel. 1991. *Constructionism.* Ablex Publishing, Westport, CT, US.

[8] Yasmin Kafai, Chris Proctor, and Debora Lui. 2019. From Theory Bias to Theory Dialogue: Embracing Cognitive, Situated, and Critical Framings of Computational Thinking in K-12 CS Education. In *Proceedings of the 2019 ACM Conference on International Computing Education Research*, ACM, Toronto ON Canada, 101–109. https://doi.org/10.1145/3291279.3339400

[9] John Maloney, Mitchel Resnick, Natalie Rusk, Brian Silverman, and Evelyn Eastmond. 2010. The Scratch Programming Language and Environment. *ACM Trans. Comput. Educ.* 10, 4 (November 2010), 1–15. DOI:https://doi.org/10.1145/1868358.1868363

[10] Randi Williams. 2021. How to train your robot: project-based ai and ethics education for middle school classrooms. Proceedings of the 52nd ACM Technical Symposium on Computer Science Education. 2021. 1382–1382.

[11] Evan W Patton, Michael Tissenbaum, and Farzeen Harunani. 2019. MIT app inventor: Objectives, design, and development. *Computational thinking education* (2019), 31–49.

[12] Golnaz Arastoopour Irgens, Cinamon S. Bailey, and Tolulope Famaye. 2022. Critical Machine Learning for Young Learners. https://idealab.sites.clemson.edu/iced.html

[13] Derman Bulut, Yavuz Samur, and Zeynep Cömert. 2022. The effect of educational game design process on students' creativity. *Smart Learn. Environ.* 9, 1 (December 2022), 8. https://doi.org/10.1186/s40561-022-00188-9

[14] Matheus V Valenza, Isabela Gasparini, and Marcelo da S. Hounsell. 2019. Serious game design for children. *Journal of Educational Technology & Society* 22, 3 (2019), 19–31.

[15] James Paul Gee. 2005. Learning by design: Good video games as learning machines. *E-learning and Digital Media* 2, 1 (2005), 5–16.

[16] Serdar Çiftçi. 2018. The Studies on Educational Digital Games Regarding Children: A New Word Analysis Approach. *Turkish Online Journal of Educational Technology-TOJET* 17, 2 (2018), 158–168.

[17] Jennifer L. Miller and Carly A. Kocurek. 2017. Principles for educational game development for young children. *Journal of Children and Media* 11, 3 (July 2017), 314–329. https://doi.org/10.1080/17482798.2017.1308398

[18] Kout Yacine. 2017. "Counter narratives of war in video games." International Critical Media Literacy Conference. 13. (February 2017) https://digitalcommons.georgiasouthern.edu/criticalmedialiteracy/2017/2017/13

[19] Franca Garzotto. 2014. Interactive storytelling for children: a survey. IJART 7, 1 (2014), 5. https://doi.org/10.1504/IJART.2014.058940

[20] Trystan Loustau and Sharon Lynn Chu. 2022. Characterizing the research-practice gap in children's interactive storytelling systems. *International Journal of Child-Computer Interaction* 34, (December 2022), 100544. https://doi.org/10.1016/j.ijcci.2022.100544

[21] Selma Rizvic, Dusanka Boskovic, Vensada Okanovic, Sanda Sljivo, and Merima Zukic. 2019. Interactive digital storytelling: bringing cultural heritage in a classroom. *J. Comput. Educ.* 6, 1 (March 2019), 143–166. https://doi.org/10.1007/s40692-018-0128-7

[22] Lappe and Dwyer. 2022. Using Interactive Storytelling to Teach Key Vocabulary Terms. (March 2022). https://www.edutopia.org/article/using-interactive-storytelling-teach-key-vocabulary-terms/

[23] Ilaria Mariani, Mariana Ciancia, and Judith Ackermann. 2022. Interactive Digital Narratives: Counter-Hegemonic Narratives and Expression of Identity. https://www.gamejournal.it/n-112023-idn/

[24] Richard Miller, Katrina Liu, and Arnetha F. Ball. 2020. Critical Counter-Narrative as Transformative Methodology for Educational Equity. *Review of Research in Education* 44, 1 (March 2020), 269–300. https://doi.org/10.3102/0091732X20908501

[25] Nina Iten and Dominik Petko. 2016. Learning with serious games: Is fun playing the game a predictor of learning success? *British Journal of Educational Technology* 47, 1 (2016), 151–163.