The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #40996

Board 320: Integrating Playful Learning: A Mixed-Reality Approach to Enhance Computational Thinking in Young Learners

Dr. Jaejin Hwang, Northern Illinois University

Dr. Jaejin Hwang, is an Associate Professor of Industrial and Systems Engineering at NIU. His expertise lies in physical ergonomics and occupational biomechanics and exposure assessment. His representative works include the design of VR/AR user interfaces to minimize the physical and cognitive demands of users. He specializes in the measurements of bodily movement as well as muscle activity and intensity to assess the responses to physical and environmental stimuli. In this project, he will lead multimodal behavioral data collection, processing, and analyses to assess children's learning and affective behaviors.

Mohammad Faizan Sohail, Northern Illinois University

Integrating Playful Learning: An Augmented Reality Approach to Enhance Computational Thinking in Young Learners

Jaejin Hwang[1]*, Yanghee Kim[2], Sungchul Lee[3], Joshua Mosher[4], Nikitha Koradala[5], and Mohammad Faizan Sohail[1]

[1] Department of Industrial and Systems Engineering, College of Engineering and Engineering Technology, Northern Illinois University, DeKalb, IL

[2] Department of Educational Technology, Northern Illinois University, DeKalb, IL

[3] Division of Computer Science and Engineering, Sunmoon University, South Korea

[4] Department of Computer Science, University of Wisconsin-Whitewater, Whitewater, WI

[5] Department of Operations Management and Information Systems, Northern Illinois University, DeKalb, IL

jhwang3@niu.edu

Abstract

This study aimed to develop a pioneering augmented reality (AR) environment focused on nurturing early computational thinking skills in kindergarten through second-grade students. Rooted in embodied cognition and social robotics, the project seamlessly integrated AR technology with a physically embodied robot named Linibot. Children engaged in a chessboard-like grid navigation, guided by Linibot through a tablet displaying AR obstacles. The educational objectives encompassed building STEM problem-solving skills, understanding symbols and sequences, and fostering confidence in technology utilization. Pre- and post-tests were employed to assess the impact of the AR environment on computational thinking skills within an intervention group. Developed and refined iteratively over two and a half years, the environment underwent testing with thirty-five children in diverse settings, including a showcase event involving twenty children. The ongoing analysis of interaction logs aims to evaluate children's performance, refine AR obstacles and robot cues, and present findings in this poster session for discussions on implications for developmentally appropriate learning and ecologically valid assessment. Preliminary results from five students in the intervention group revealed improvements in task performance related to path-finding tasks compared to the pre-test. The average duration of task completion decreased by 42%, the average number of instances of avoiding difficult problems substantially decreased by 80%, and the number of missions achieved increased by 80%. This impact was more pronounced for students who faced greater challenges during the pre-tests. The preliminary findings suggest that the proposed AR educational tool not only enhanced students' computational thinking but also influenced their learning behavior, encouraging them to tackle difficult problems rather than avoid them. Future studies will conduct a comparative analysis between the control and intervention groups to rigorously understand the intervention's impact.

1. Introduction

According to the National Science Board, the demand for STEM skills in jobs is expected to rise by 2026 [1]. However, K-12 mathematics and science performance in the United States has not shown improvement and lags behind other countries [2]. The report emphasizes the persistent underrepresentation of gender and ethnic minorities in the STEM workforce. The COVID-19 pandemic has further exacerbated challenges in fostering equitable development of young STEM talents [3]. The shift to online education and work due to shelter-in-place measures has become widespread, but the Northwest Evaluation Association predicts a negative impact on academic growth, particularly in mathematics [4]. This effect is anticipated to be more severe for younger children in elementary school and those from low-income families or of color [5].

Existing online learning approaches may fall short in meeting the needs of young children, as noted by educators and principals who emphasize the importance of resources that involve hands-on activities and promote social and emotional learning [6]. Recognizing that children naturally interact with their surroundings using multiple senses, STEM learning environments should align with this by engaging children cognitively, socially, emotionally, and physically [7]. Positive early experiences in STEM tasks play a vital role in cultivating a positive STEM identity and fostering continued interest in STEM fields [8]. Exploring innovative applications of advanced technologies becomes crucial in providing equitable STEM learning opportunities for all children, irrespective of their real-life circumstances.

The objective of the project team was to encourage children to perceive technology as a valuable tool for play, learning, and daily activities, enabling them to develop proficiency in both creating and using advanced technology. The vision involved integrating emerging technologies to establish a personalized STEM learning environment tailored for children. Research indicated that young children willingly participated in interactions with digital virtual characters and robots, forming social connections with these technological entities [9].

The aim of this study was to create an innovative mixed-reality environment, merging a socially interactive humanoid robot with AR to facilitate computational tasks for children in K-2 while engaging in play with the robot. This hands-on experience sought to assist children in grasping crosscutting and foundational concepts of STEM literacy and problem-solving, including sequences and symbols. Rooted in embodied cognition and culturally responsive/sustainable pedagogy, the environment aimed to offer an equitable AR-enhanced play experience featuring a non-judgmental and socially unbiased robot playmate. The goal was to foster positive attitudes towards working with and on advanced technologies.

The study's particular objectives involve testing and comparing the feasibility of an embodied AR system between the control and intervention groups. Pre- and post-tests will be administered for each group to assess the impact of the AR system on children's task performance. The hypothesis posited that the AR system would improve children's performance in path-finding tasks, attributed to heightened assistance in spatial awareness and social support provided by a social robot.

2. Methods

2.1. Augmented Reality Learning Tool

The objective of this study was to develop an innovative AR environment that promotes the early cultivation of computational thinking. Children in K-2 were tasked with walking on a floor mat designed as a 5x5 chessboard, assisting a robot named Linibot in navigating a path to a destination while holding a tablet. Linibot provided guidance through instructions, cues, and feedback, encompassing corrections and motivational encouragement. The tablet concurrently displayed a corresponding map and AR obstacles for the child to navigate around.

The key learning objectives of this study were to enhance children's foundational STEM problem-solving skills, specifically focusing on their comprehension of symbols and sequences applicable across various STEM domains, and to boost their confidence in utilizing advanced technology. To non-intrusively assess children's progress while engaged in the mixed-reality environment, we collected automated interaction logs capturing their walking path and time taken to reach the goal. The iterative development of the mixed-reality environment spanned a year and a half, with continuous testing of designs involving 25 children in diverse informal settings, including our lab, a community center, and a STEM showcase event. The testing focus varied based on the developmental stage of the environment at each instance.

2.2.Participants

At a local elementary school, we enlisted fifteen children for the intervention group (8 males and 7 females) and eight children for the control group (5 males and 3 females). All participants were second-grade students, representing diverse ethnicities such as Caucasian, Asian, and African American. Parental consent approved by IRB was obtained from children’s parents or teachers.

2.3.Experimental Procedures

On the initial day, both the control and intervention groups took part in pre-tests conducted at desks using a customized app on tablets. Children received instructions through a standard instructional video and then engaged in path-finding tasks displayed in a 2D setting on the tablet. From days 2 to 4, the intervention group experienced our AR educational tools. In this tool, each child played a path-finding game where a social robot greeted them with programmed utterances upon approaching the game. These utterances, controlled by a human operator behind the scenes, provided encouragement when a child faced challenges during the game. The robot could also move, controlled by the human operator using a tablet controller, acting as a peer following the child's path without interfering. On day 5, both the control and intervention groups participated in post-tests.

2.4.Data Analysis

Interaction logs served as the basis for assessing each child's walking path, total distance traveled, and time taken to reach the goal. This evaluation extended to each subtask involving finding a gem, where the child's travel distance and time spent were meticulously documented for each grid cell. The A* (A-Star) search algorithm was employed to determine the optimal path from the starting point to the gem, allowing for a comparison with the actual path taken by the child. These algorithms were applied to both pre- and post-tasks, as well as the AR tasks. Currently, data processing is ongoing, and analysis has been conducted on only for five participants from the intervention groups to explore differences between pre- and post-tests.

Concerning task performance, factors such as total time spent on the task, time spent per mission (gem), number of resets, number of achievements (gem), and travel distance inefficiency (%) were considered. The travel distance inefficiency was calculated by assessing the relative percentage difference between the total sum of the actual path and the total sum of the optimal path.

3. Results

3.1. Duration of the task

In the intervention group, there was a notable decrease in the average total time spent from 625 seconds during the pre-test to 362 seconds in the post-test after the introduction of the AR educational tool. Examining individual changes, three students exhibited a remarkable reduction in total time spent on tasks, amounting to a collective decrease of 803 seconds, as depicted in Figure 1. Moreover, the average time spent to complete each mission (gen) decreased from 190 seconds per mission to 41 seconds per mission. Four students experienced a notable decrease in time spent per mission, with a cumulative reduction of 148 seconds, as illustrated in Figure 1.

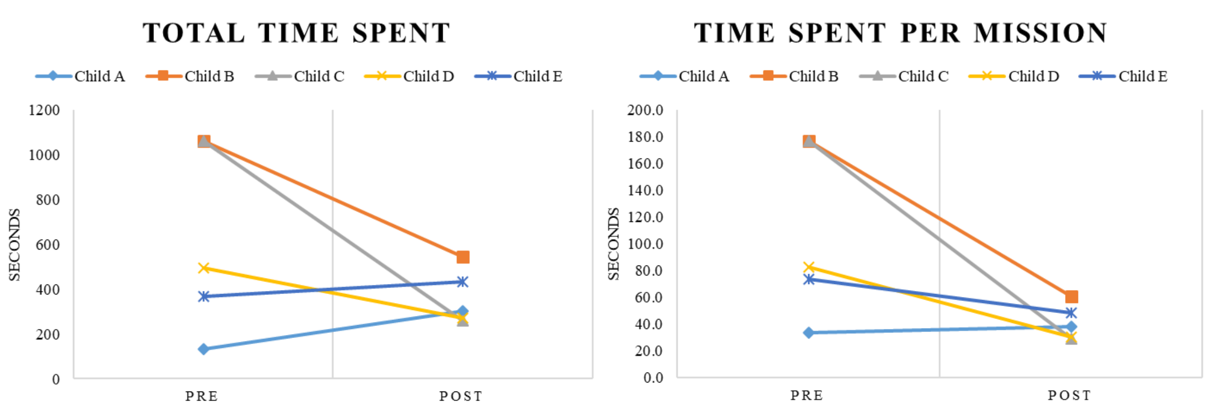

Figure 1. The total spent and time spent per mission (seconds) for individual child before and after experiencing the AR educational tool.

3.2. Number of rest and achievements

Following the AR educational tool experience, there was a substantial reduction in the average number of resets for path-finding layouts among students who gave up on solving the path and attempted new layouts. The average number of resets decreased from 7 to 1.4, reflecting a significant improvement. Four students notably decreased their number of resets by 10, as illustrated in Figure 2. Additionally, there was an increase in the average number of achievements, rising from 5 to 9 gems. The number of achievements represents the gems students were able to collect, and all five students achieved more gems, with an increase of up to 4 compared to the pre-test, as shown in Figure 2.

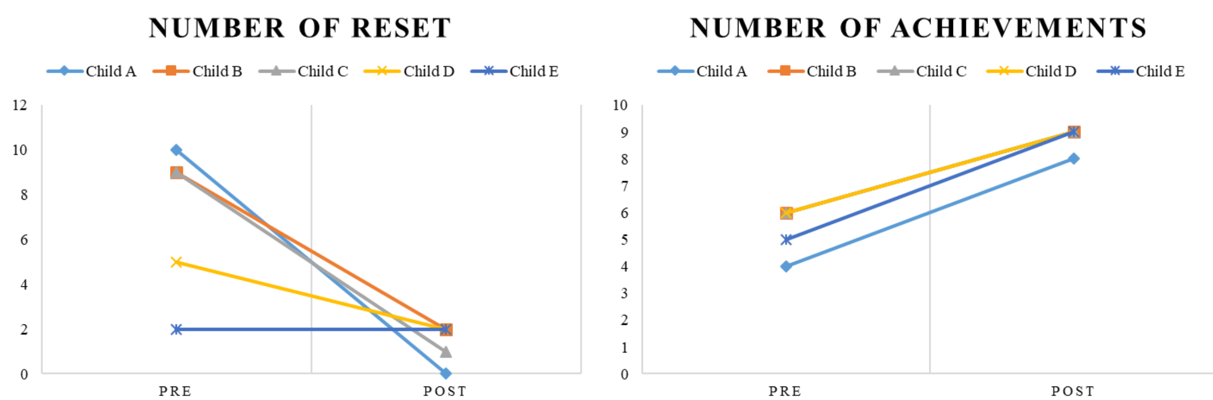

Figure 2. The number of resetting the path finding layouts and the number of achievements to acquire the gem before and after the AR educational tool.

3.3.Total Distance Inefficiency

The average total distance inefficiency (%) witnessed a decrease from 144% to 141% after the implementation of the AR educational tool. Notably, three students achieved a substantial reduction in total distance inefficiency, marking a collective decrease of 37% compared to the pre-test, as depicted in Figure 3.

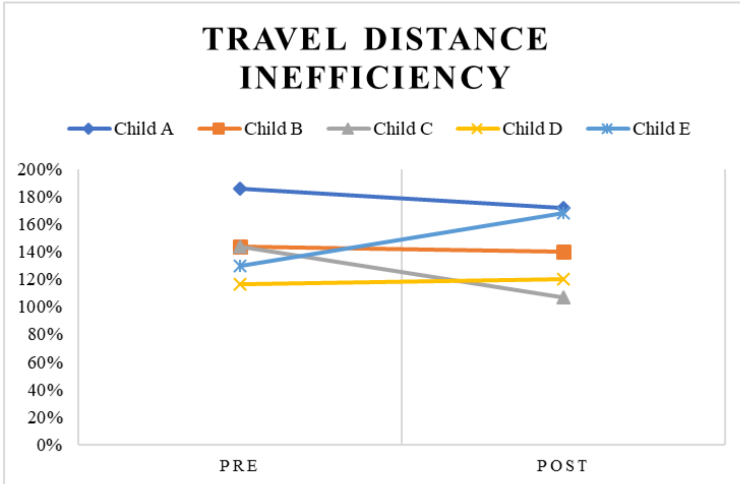

Figure 3. Travel distance inefficiency (%) of individual child before and after implementing the AR educational tool.

4. Discussion

This study created an AR-based education tool in collaboration with a social robot to boost the computational thinking of young children. The research focused on evaluating the impact of the AR tool on their task performance, specifically in path-finding tasks. The results indicated a positive effect, as students demonstrated improved performance in completing missions with reduced time. Additionally, they exhibited greater persistence in problem-solving, showing a preference for modifying path layouts rather than resetting the game.

Following a 4-day implementation of the AR educational tool, there was a significant improvement in students' performance in the path-finding task. The embodied learning experience associated with this task contributed to an enhanced understanding of computational thinking. Beyond merely observing the layout on the tablet, students actively engaged by physically moving to the correct cell on the grid. This necessitated spatial awareness in three-dimensional space, and a noticeable improvement in performance was observed over the course of the AR task. These advancements suggest potential benefits for increased task performance in subsequent post-test settings.

Variability existed in the degree of improvement observed before and after the implementation of the AR educational tool. While some students exhibited significant enhancements in performance, others experienced relatively modest improvements. Notably, substantial progress was more frequently observed in students who initially faced greater challenges. For instance, students B and C, who had the longest completion times during the pre-test, demonstrated the most dramatic reductions in time during the post-test. This suggests that the effectiveness of the AR educational tool varied among individual children, with those encountering greater difficulties initially benefiting more significantly from the learning experience it offered.

A noteworthy discovery emerged regarding the substantial decrease in the number of resets from the pre-test to the post-test phase. During the pre-test, students frequently opted to give up on challenging problems, resorting to the "erase" button to reset the layout of the path-finding tasks. Some students even utilized the reset button up to 10 times until encountering an easier problem. This behavior underwent a significant reduction following the introduction of the AR educational tool. The number of resets now fluctuated between 0 and 3, indicating that students exhibited increased persistence in problem-solving. Moreover, they displayed greater motivation to confront difficult problems rather than resorting to frequent resets.

Modifications in students' learning behavior were potentially influenced by the social robot integrated into our AR educational tool. In instances where students faced challenges in problem-solving, the social robot offered friendly verbal suggestions accompanied by relevant facial expressions. Additionally, the robot provided cheers and encouragement to students as they made progress. This interactive experience aimed to foster students' confidence and motivation, encouraging them to tackle complex problems rather than succumbing to the inclination of giving up and resetting the task.

In contrast to other measures of task performance, the inefficiency in travel distance exhibited limited changes between pre- and post-tests. This observation may be attributed, in part, to the number of attempts students made to reset the layout in both phases. During pre-tests, students frequently reset the layout until they encountered a simpler problem, potentially leading to a travel path closer to the optimal one. Conversely, in post-tests, students prioritized facing and overcoming challenging issues rather than resorting to layout resets. Consequently, their actual paths often deviated from the optimal path. In summary, while the travel inefficiency results appear similar between pre- and post-tests, students likely tackled more challenging and intricate problems in the post-test phase, demonstrating a willingness to confront difficulties rather than avoid them.

The initial findings from these results suggest that the AR educational robot tool, coupled with a social robot, effectively enhances the computational thinking of young children. A four-day exposure to this system led to a reduction in the time students took to accomplish path-finding tasks, fostering motivation to tackle challenging problems rather than avoiding them. This underscores the significance of embodied learning and social support as crucial factors in improving both students' learning outcomes and their motivation to solve complex problems. Notably, the tool's impact was more pronounced among students facing initial challenges, aligning with its intended purpose of aiding underrepresented minority groups in STEM fields with limited access to resources. The installation of the customized app on tablets, along with the simple integration of QR codes into mats, makes this system versatile for implementation in classrooms, libraries, or STEM event areas.

Despite the careful design and execution of this study, several limitations have been identified. The evaluation in this paper focused solely on the five participants in the intervention group, and a comparative analysis between the control and intervention groups is pending as we are currently processing the data. The application of the proposed system was confined to second-grade elementary school students, limiting the generalizability of the results to other grade levels. Given the difficulty level of our AR tasks, the appropriate target audience would range from first to third-grade students. To minimize confounding variables related to educational levels, this study focused solely on second-grade students. Future research could investigate first and third-grade students as a stratified cohort to evaluate the effectiveness of the AR educational tool. Due to the limited sample size in this preliminary phase, a formal statistical analysis was not undertaken. Subsequent studies will encompass data from all fifteen participants, and a comprehensive statistical analysis will be conducted to ascertain the statistical significance of the measures.

5. Conclusion

This study introduced a distinctive embodied AR educational tool featuring a social robot designed to enhance the computational thinking skills of young children, specifically focusing on solving path-finding problems for second-grade elementary school students. The preliminary results indicate significant improvements in students' task performance, including reduced time spent on tasks and an increased number of missions achieved. Moreover, there was a notable rise in their motivation to solve problems, as evidenced by a higher frequency of tackling difficult problems rather than avoiding them, following consistent exposure to the proposed AR educational tools. The impact of the tool was particularly pronounced for students who initially faced challenges with the concepts, suggesting that embodied learning and social support from a robot peer play crucial roles in enhancing both the learning capabilities and behaviors of young children.

References

[1] J. F. Sargent Jr, "The US science and engineering workforce: Recent, current, and projected employment, wages, and unemployment," 2017, Accessed: Jan. 23, 2024. [Online]. Available: https://ecommons.cornell.edu/handle/1813/78162

[2] N. R. Council, *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. National Academies Press, 2011. Accessed: Jan. 23, 2024. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=kTNO_YZvBmsC&oi=fnd&pg=PR1&dq=However,+K-12+mathematics+and+science+performance+in+the+United+States+has+not+shown+improvement+and+lags+behind+other+countries.+&ots=Zncq-HznGa&sig=0Z7VcBtd_gPSMTQCHvFh_0Bj4Aw

[3] W. M. Purcell and J. Lumbreras, "Higher education and the COVID-19 pandemic: navigating disruption using the sustainable development goals," *Discov. Sustain.*, vol. 2, no. 1, p. 6, Dec. 2021, doi: 10.1007/s43621-021-00013-2.

[4] C. Courtemanche, J. Garuccio, A. Le, J. Pinkston, and A. Yelowitz, "Strong Social Distancing Measures In The United States Reduced The COVID-19 Growth Rate: Study evaluates the impact of social distancing measures on the growth rate of confirmed COVID-19 cases across the United States.," *Health Aff. (Millwood)*, vol. 39, no. 7, pp. 1237–1246, Jul. 2020, doi: 10.1377/hlthaff.2020.00608.

[5] T. Leventhal and J. Brooks-Gunn, "A randomized study of neighborhood effects on low-income children's educational outcomes.," *Dev. Psychol.*, vol. 40, no. 4, p. 488, 2004.

[6] L. Darling-Hammond, A. Schachner, and A. K. Edgerton, "Restarting and Reinventing School: Learning in the Time of COVID and Beyond.," *Learn. Policy Inst.*, 2020, Accessed: Jan. 23, 2024. [Online]. Available: https://eric.ed.gov/?id=ED610890

[7] P. W. Garner, N. Gabitova, A. Gupta, and T. Wood, "Innovations in science education: infusing social emotional principles into early STEM learning," *Cult. Stud. Sci. Educ.*, vol. 13, no. 4, pp. 889–903, Dec. 2018, doi: 10.1007/s11422-017-9826-0.

[8] A. Y. Kim, G. M. Sinatra, and V. Seyranian, "Developing a STEM Identity Among Young Women: A Social Identity Perspective," *Rev. Educ. Res.*, vol. 88, no. 4, pp. 589–625, Aug. 2018, doi: 10.3102/0034654318779957.

[9] M. M. A. De Graaf, "An Ethical Evaluation of Human–Robot Relationships," *Int. J. Soc. Robot.*, vol. 8, no. 4, pp. 589–598, Aug. 2016, doi: 10.1007/s12369-016-0368-5.