Fostering Early Science Learning Through an Interactive Desktop Game for Preschool Children

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ABSTRACT

This study presents the design, development, and usability evaluation of an interactive desktop game aimed at fostering early science learning among preschool children. Recognizing the limitations of conventional teaching methods in engaging young learners, the game integrates visual storytelling, interactive tasks, and science-themed content grounded in play-based pedagogy. Developed using the Waterfall model and implemented through RPG Maker XP, the game features animated characters, voice-guided instructions, and scaffolded activities to support embodied cognition and minimize cognitive load. A usability testing session involving ten preschool children (aged 5–6) and their parents was conducted to assess the game's effectiveness in delivering science concepts and maintaining engagement. Results revealed strong positive feedback regarding visual appeal, instructional clarity, and ease of use. Parents reported that the game successfully supported children's ability to navigate tasks independently and reinforced learning through guided exploration. Minor suggestions were made for increased interactivity in visual elements and additional instructional support for novice users. These findings are consistent with recent literature emphasizing the role of interactivity, dual-modality instruction, and visual coherence in digital learning environments. Overall, the study affirms the game's potential as a developmentally appropriate tool to enhance scientific curiosity and foundational understanding among preschool learners. Recommendations for future iterations include incorporating real-time animated content, guided tutorials, and personalized feedback mechanisms.

Keyword: Early Childhood Science Education, Interactive Learning Games, Preschool Digital Learning, Embodied Cognition and Cognitive Load Theory

INTRODUCTION

Understanding the importance of science is essential for navigating the complexities of the modern world. Science equips individuals with the ability to comprehend natural phenomena, develop technological innovations, and address critical global challenges such as climate change, sustainability, and public health crises. As emphasized by [1], [2], the increasing demand for individuals with critical thinking, creativity, adaptability, and problem-solving abilities has made science education a global priority across all levels of education, including early childhood.

Despite concerted efforts by educators and researchers to make science more accessible and engaging, there remains a significant challenge in capturing the interest of young learners—particularly preschoolers [3]. At this formative stage, conventional teaching approaches are often difficult in stimulating curiosity and enthusiasm for scientific exploration [4]. Addressing this gap requires the adoption of innovative,

developmentally appropriate strategies that make science both enjoyable and comprehensible. This study introduces the design and development of an interactive desktop game aimed at supporting self-directed science learning among preschool children. The game incorporates playful interactions, visual storytelling, and foundational scientific concepts.

LITERATURE REVIEW

Importance of Play-Based Digital Learning in Early Science

Digital and interactive play supports cognitive and socio-emotional development in preschoolers. A scoping review by [5], [6] categorizes "play-based pedagogy" as the most widely used approach in early childhood digital learning children learn science and problem-solving effectively when digital tools are integrated into play scenarios. Interactive desktop games offer embodied cognitive experiences that are vital for concrete learners. A study by [7] found that digital games that emphasize embodied cognition where learners physically interact with the desktop interface lead to significant gains in cognitive outcomes (effect size $d \approx 0.67$) compared to traditional instruction. In the context of digital games, embodied cognition refers to learning experiences that go beyond visual or auditory input, requiring learners to engage in physical or motor actions such as using a mouse to drag objects, clicking to trigger cause-and-effect relationships, or sequencing events [8]. These interactive actions help anchor abstract scientific concepts (e.g., cause and effect, size, quantity, or classification) in concrete, hands-on experiences.

Efficacy of Digital Science Games on Problem Solving and Creativity

STEM stands for Science, Technology, Engineering, and Mathematics. In early childhood education, STEM activities help children explore the world around them through hands-on experiments, problem-solving, and creative thinking. Digital science games designed with STEM elements can foster these skills in fun and engaging ways [9]. A growing body of research highlights the potential of digital science games to significantly enhance both problem-solving and creative thinking in early childhood, where STEM skills begin to take root. Digital games create immersive environments filled with challenges, feedback loops, and scaffolded tasks ideal for fostering problem-solving competencies. A meta-analysis by [9] also found that digital STEM games yielded stronger effects on problem-solving skills than on declarative knowledge. Beyond meta-analysis, games like block-based programming puzzles (e.g., codeSpark Academy) have been shown to reliably measure and improve both computational thinking and real-world problem-solving, as evidenced in studies where gameplay behaviors mapped onto validated assessments [10].

Interactivity and Cognitive Load

In digital learning environments, interactivity, especially when self-paced, plays a key role in managing cognitive load and optimizing learning. According to Cognitive Load Theory, learners have limited working memory capacity, so instructional designs should minimize unnecessary mental strain while promoting meaningful processing [11]. In interactive digital games, features such as click-to-progress, drag-and-drop, and self-controlled pacing reduce extraneous load—the mental effort imposed by poorly structured content—allowing children to focus more on germane load, which is directly linked to learning and schema formation [12]. A 2023 meta-analysis of embodied learning interventions found that activities involving meaningful bodily engagement such as manipulating game elements—can lower cognitive load and enhance comprehension and retention [13]. Moreover, a 2024 meta-analysis of game-based learning in early childhood reported moderate to large positive effects on cognitive outcomes, in part due to interactive elements that direct attention to essential content and encourage active mental engagement [14]. Thus, well-designed interactivity not only makes learning more engaging but also strategically manages cognitive resources, enabling preschoolers to process scientific concepts more deeply and effectively.

METHODOLOGY

The project employed the Waterfall model, which is a systematic and organised approach to software development. It provides precise milestones and well-defined deliverables. The phases encompassed in the process are the original needs planning, development, testing, and deployment (Naga, Kumar, Sathvika, 2018).

Planning

The planning phase is a critical component in the development of the Interactive Desktop Game for Preschool Children for science subject, as it establishes the foundational concepts necessary for effective and efficient implementation. This phase outlines the key project requirements, including the problem statement, project scope, and initial objectives. An application architecture was formulated, detailing the technological specifications and modular components utilized in the system. A comprehensive explanation of these elements is provided in the subsequent section.

Application Architecture

A well-defined application architecture provides the structural foundation that supports effective integration of educational mechanics, multimedia elements, and interactive features in a preschool desktop game. Research shows that coherent technical frameworks—characterized by modular design and clear interaction flows—enhance performance, usability, and cognitive efficiency in digital educational games. The application architecture of the interactive desktop base game for science subject of preschool students presented in Figure 2.1.

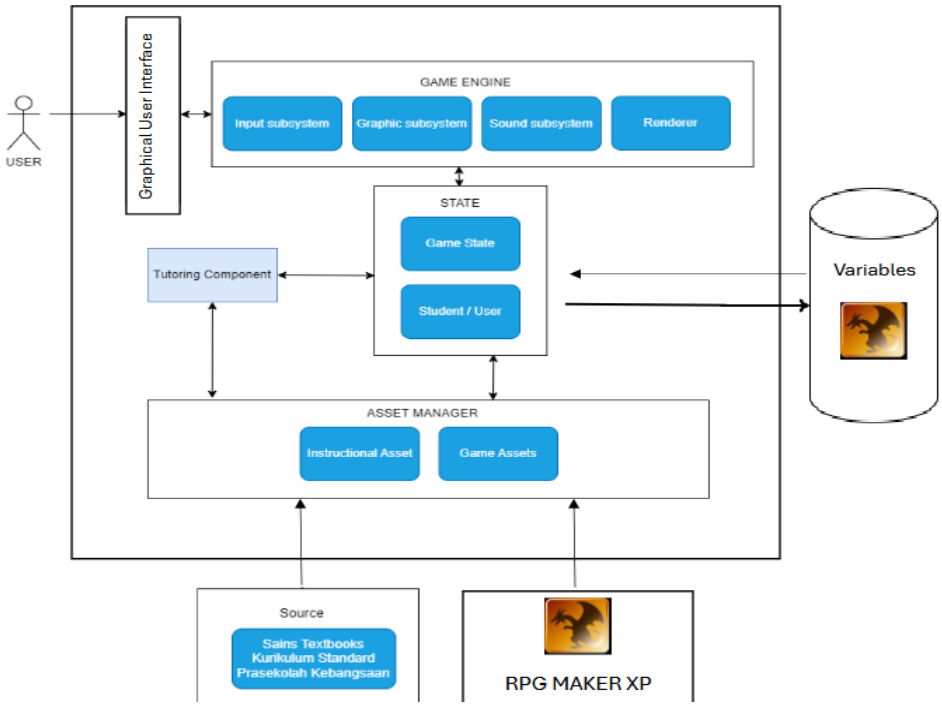

Figure 2.1 Application architecture.

Application architecture in Figure 2.1 shows that through a Graphical User Interface (GUI) connected to the Game Engine, users interact with the system in real time. The Input Subsystem manages user inputs received via the GUI, while the Graphic Subsystem handles graphical rendering. The Sound Subsystem controls audio output, and the Renderer is responsible for transforming game data into visual representations. These four subsystems collectively form the core components of the Game Engine. Another key element is the State Component, which monitors user progress and current Game State. Complementing this is the Tutoring Component, which continuously references these states to provide real-time feedback and adapt instructional content based on individual performance. The Asset Manager supports this process by managing both Game Assets (such as textures, models, and audio) and Instructional Assets (learning materials and displayed information).

The Game Engine ensures smooth internal data flow by synchronizing user input, game state updates, and asset deployment. The Tutoring Component utilizes data from the State Component to personalize learning experiences, while the Asset Manager supplies required assets on demand to both the Game Engine and the tutoring module. This architecture emphasizes instructional support and visual engagement without delving

into advanced technologies like machine learning. Moreover, the design focuses strictly on the system's core functionality, excluding aspects such as payment gateway integration or software maintenance processes. This ensures a secure, distraction-free learning environment tailored specifically for young users engaging in educational content.

Development

The technical implementation of Interactive Desktop Game for Preschool Children for science subject is a crucial step in the project development process. The design of the central character crafted with Clip Studio Paint, emphasizing its visual charm and attractiveness for preschool-aged children as presented in Figure 2.2. The design of the character features vibrant colors and cheerful expressions to inspire curiosity and camaraderie, enhancing the learning experience [14]. The desktop application was developed using RPG Maker XP because it enables them to use required scripting tools which are crucial for events and animations along with game mechanics.

Figure 2.2: Design of main characters

The game provides educational interactions within the game as a guide for the players to request scientific explanations from plants and animals while performing learning activities. Children can naturally explore information through interactive sessions which also spark their curiosity. The game provides instruction and dialog that enhances children's learning through fun activities to maintain engagement between learners [15]. The UI of the game manipulates interactive colours, pictures and environment that suitable with the preschool science topic which is about animals and plants. main interface is presented in Figure 2.3. According to Cognitive Load Theory, learners have limited working memory capacity, so instructional designs should minimize unnecessary mental strain while promoting meaningful processing [11]. Thus the game provide three simple button for the children to starts, continue (if they have started the game before) or exit from the game.

Figure 2.3: The main page of the game

The game provides two level, where the children that complete the easy module will continue to advance module. The design and layout of each model is different as it been proved that will enhance children engagement [14]. The

Figure 2.4: The interface of easy and advance level.

While for audio, the character's voices are trained with AI using voice.ai. The process starts with AI voice model training, then the voices are integrated with the character in RPG Maker XP. The voices include the instruction to the player, the questions that are asked by the main characters as well as the explanation about animals and plants with storytelling manner.

Testing

A usability testing session was conducted with ten preschool children aged five to six years. The researchers approached parents in a public area and obtained verbal consent to invite their children to participate in the game testing session. Upon receiving agreement from both parents and children, the researchers presented the interactive desktop game on a laptop, allowing the children to freely explore and engage with the game. Parents remained present throughout the session to observe and provide support as needed.

Two separate questionnaires were prepared to collect feedback: one for the children and one for the parents. Parents were invited to complete their questionnaire by scanning a QR code provided by the researchers. For the child participants, the researchers verbally administered the questionnaire and recorded the children's responses on their behalf to accommodate their developmental abilities.

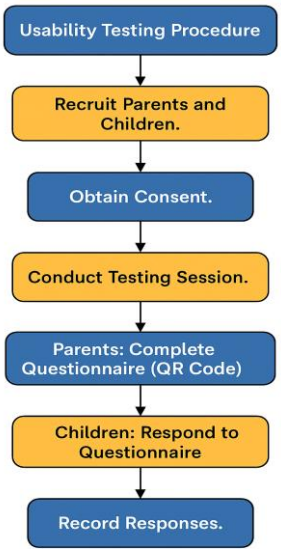

Figure 2.5: Testing procedure.

RESULTS AND DISCUSSION

A quantitative usability evaluation was conducted to assess the effectiveness of the game's educational features and interactive elements for young users. The questionnaire was structured to differentiate between usability-specific aspects such as navigation ease, clarity of instructions, and responsiveness of interactive components and broader dimensions of the overall user experience. The results of the usability testing conducted with ten children are presented in Figures 3.1 through 3.4.

Figure 3.1 Attractiveness of Animal and Plant Knowledge (Preschooler).

Figure 3.1 presents the evaluation results concerning children's interest in the gamified educational components related to animal and plant content. Four participants strongly agreed that the theme was attractive, two agreed, one was neutral, two disagreed, and one strongly disagreed. Feedback from participants who expressed disagreement indicated that the static nature of the animal characters reduced interactivity and realism. This aligns closely with recent findings in the literature. For example, a 2024 study in the Journal of Science Education and Technology revealed that pure animated sequences produced very strong learning effects (Cohen's d = 1.34) compared to static visuals or animations with presenters (d ≈ 0.70) [16]. The underlying mechanism appears to be improved attention as measured by eye-tracking animated visuals kept learners more focused on key content, whereas animated presenters introduced extraneous cognitive load, diluting the instructional impact. This result was considered constructive by the researchers, who recommend that future game designs targeting preschool learners incorporate animated elements or recorded videos to better simulate real animals. Enhancing understanding through such features is essential for increasing engagement and improving learning outcomes in digital educational games for young children.

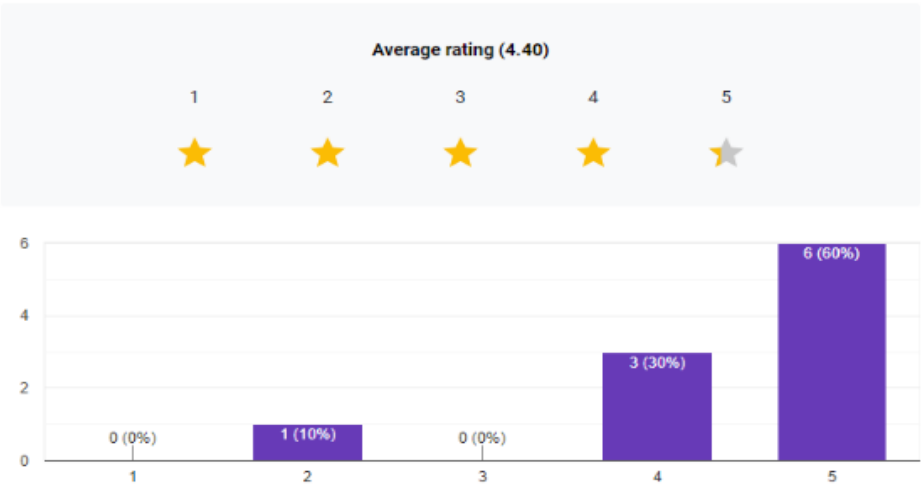

Figure 3.2 Clarity of Game Rules (Preschooler).

According to Cognitive Load Theory, learners possess limited working memory capacity; therefore, instructional design should aim to minimize unnecessary cognitive demands while facilitating meaningful information processing [11]. As such, the clarity and accessibility of instructions were key elements evaluated in this project. Survey results revealed that six children strongly agreed and four agreed that the game instructions were simple and easy to understand. This outcome echoes findings in educational game research. For instance, [17] underscore that the timing and modality of information presentation are crucial: presenting instructions *before* gameplay (pre-training) or *just-in-time* during gameplay can significantly manage cognitive load and enhance comprehension. Based on these findings, the researchers concluded that presenting instructions in two formats text-based guidance and voice narration effectively supports young learners by accommodating different literacy levels, reduce extraneous cognitive load and promote effective learning in early learners [18]. However, two children disagreed, noting that they required parental assistance to navigate and play the game. To address this, future enhancements should consider incorporating guided verbal walkthroughs, on-screen helper prompts, or introductory video tutorials that children can engage with prior to starting the game.

The evaluation of visual attractiveness, as illustrated in the figure 3.3, shows that six guardians strongly agreed and four agreed that the game's visual design was appealing. This positive response indicates that the game successfully captured the attention of both preschoolers and their adult supervisors. Such findings align with recent research emphasizing the critical role of visual elements in children's educational media, where effective design enhances attention, engagement, and information retention [19]. A study by [20]further supports this, showing that parental approval is strongly influenced by visual aesthetics, which in turn affects their willingness to support children's use of digital games. Therefore, the high ratings from parents in this study not only validate the aesthetic appeal of the game but also underscore the importance of maintaining visual quality to support user engagement, usability, and educational effectiveness.

Figure 3.3 Game Design Attractiveness (Guardian/Parent)

Figure 3.4 illustrates parents' perceptions of their children's ability to learn science through the game, where six parents agreed and four strongly agreed that their children could master game mechanics quickly, with four assigning the maximum score of five for ease of play and six rating it a four. This overwhelmingly positive feedback aligns with findings in user-acceptance research, which emphasize perceived ease of use as a key determinant for adoption of educational technologies especially in interactive contexts designed for young learners [9]. In particular, [21]highlight the importance of effort expectancy users' belief that the technology requires minimal effort which greatly influences acceptance in educational environments. Similarly, a meta-analysis of digital game-based learning in STEM education reported that interactive games significantly outperform traditional teaching methods in terms of cognitive learning outcomes (effect size $d \approx 0.67$), an effect largely attributed to game elements that facilitate immediate feedback, active problem-solving, and intuitive interaction [7]. This study's findings not only provide empirical confirmation of parents' belief in the game's learnability but also suggest that well-designed interactivity and usability features effectively lower

barriers to engagement and mastery. Future game development should continue to emphasize intuitive interfaces and real-time guidance to maintain learning momentum and minimize cognitive load for both children and supervising adults.

Figure 3.4 Learning ability through the game (Guardian/Parent)

CONCLUSION

The results of this usability study demonstrate that the interactive desktop game was well-received by both preschool children and their guardians, particularly in terms of visual appeal, instructional clarity, and ease of use. The majority of participants found the game engaging and accessible, with positive feedback indicating that the game effectively supported early science learning. Minor usability challenges—such as the need for greater interactivity in certain visual elements and additional instructional scaffolding—offered valuable insights for iterative improvement. These findings align with recent research highlighting the importance of visual engagement, multimodal instructions, and intuitive interfaces in digital educational tools for young learners. The results affirm the game's potential as a developmentally appropriate tool to foster interest, engagement, and early scientific understanding in preschool-aged children. Future enhancements should focus on incorporating more dynamic visuals, personalized feedback, and optional guided walkthroughs to further optimize the learning experience.

REFERENCES

1. R. Fitri, "Pentingnya Pendidikan Sains Bagi Perkembangan Kognitif Dan Kreatifitas Anak Usia Dini," Harmon. Pendidik. J. Ilmu Pendidik., vol. 1, no. 3, pp. 37–43, 2024, doi: https://doi.org/10.62383/hardik.v1i2.406.
2. M. T. Hebebci and E. Usta, "The Effects of Integrated STEM Education Practices on Problem Solving Skills, Scientific Creativity, and Critical Thinking Dispositions," Particip. Educ. Res., vol. 9, no. 6, pp. 358–379, 2022, doi: 10.17275/per.22.143.9.6.
3. J. D. Plummer, A. T. Ozcelik, and M. M. Crowl, "Informal science educators engaging preschool-age audiences in science practices," Int. J. Sci. Educ. Part B, vol. 11, no. 2, pp. 91–109, 2021, doi: 10.1080/21548455.2021.1898693.
4. H. Hunaepi, M. Ikhsan, H. Suwono, and S. Sulisetijono, "Curiosity in Learning Biology: Literature Review," Prism. Sains J. Pengkaj. Ilmu dan Pembelajaran Mat. dan IPA IKIP Mataram, vol. 9, no. 2, p. 343, 2021, doi: 10.33394/j-ps.v9i2.4272.
5. J. Ismail and N. Abdullah, "Literature Review on Integrating STEAM in Preschool : International Practices and Malaysian Implementation," Int. J. Acad. Res. Progress. Educ. Dev., vol. 13, no. 4, pp. 3286–3293, 2024, doi: 10.6007/IJARPED/v13-i4/23846.
6. H. Li, H. He, W. Luo, and H. Li, "Early Childhood Digital Pedagogy: A Scoping Review of Its

Practices, Profiles, and Predictors," Early Child. Educ. J., no. Nov, 2024, doi: 10.1007/s10643-024-01804-8.

7. A. Koç and S. Kanadlı, "Effect of Interactive Learning Environments on Learning Outcomes in Science Education: A Network Meta-Analysis," J. Sci. Educ. Technol., no. Feb, 2025, doi: 10.1007/s10956-025-10202-7.
8. X. Xu, J. Kang, and L. Yan, "Understanding embodied immersion in technology-enabled embodied learning environments," J. Comput. Assist. Learn., vol. 38, no. 1, pp. 103–119, 2022, doi: https://doi.org/10.1111/jcal.12594.
9. Y. Gui, Z. Cai, Y. Yang, L. Kong, X. Fan, and R. H. Tai, "Effectiveness of digital educational game and game design in STEM learning: a meta-analytic review," Int. J. STEM Educ., vol. 10, no. 1, 2023, doi: 10.1186/s40594-023-00424-9.
10. K. Teng and G. K. W. K. Chung, "Measuring Children's Computational Thinking and Problem-Solving in a Block-Based Programming Game," Educ. Sci., vol. 15, no. 1, 2025, doi: 10.3390/educsci15010051.
11. A. Shaban, E. Pearson, and V. Chang, "Evaluation of User Experience, Cognitive Load, and Training Performance of a Gamified Cognitive Training Application for Children With Learning Disabilities," Front. Comput. Sci., vol. 3, no. July, pp. 1–18, 2021, doi: 10.3389/fcomp.2021.617056.
12. H. Li, T. Zhang, J. D. Woolley, J. An, and F. Wang, "Exploring factors influencing young children's learning from storybooks: Interactive and multimedia features," J. Exp. Child Psychol., vol. 233, p. 105680, 2023, doi: https://doi.org/10.1016/j.jecp.2023.105680.
13. S. Klingenberg, R. Bosse, R. E. Mayer, and G. Makransky, Does Embodiment in Virtual Reality Boost Learning Transfer? Testing an Immersion-Interactivity Framework, vol. 36, no. 4. Springer US, 2024. doi: 10.1007/s10648-024-09956-0.
14. M. S. Alotaibi, "Game-based learning in early childhood education: a systematic review and meta-analysis," Front. Psychol., vol. 15, no. April, 2024, doi: 10.3389/fpsyg.2024.1307881.
15. M. Gutica and S. Petrina, "Emotional agents in educational game design: Heroes of math island," Res. Anthol. Game Des. Dev. Usage, Soc. Impact, no. 2013, pp. 411–432, 2022, doi: 10.4018/978-1-6684-7589-8.ch021.
16. J. Beautemps, A. Bresges, and S. Becker-Genschow, "Enhancing Learning Through Animated Video: An Eye-Tracking Methodology Approach," J. Sci. Educ. Technol., vol. 34, no. 1, pp. 148–159, 2024, doi: 10.1007/s10956-024-10162-4.
17. C. Nahas, M. Gandit, and E. Monfort, "Engagement in computerized cognitive training instructions by older people. A within-subject design to evaluate comprehension and acceptability of serious games instructions," Front. Aging, vol. 6, no. February, pp. 1–13, 2025, doi: 10.3389/fragi.2025.1297704.
18. A. Vasalou, L. Benton, S. Ibrahim, E. Sumner, N. Joye, and E. Herbert, "Do children with reading difficulties benefit from instructional game supports? Exploring children's attention and understanding of feedback," Br. J. Educ. Technol., vol. 52, no. 6, pp. 2359–2373, 2021, doi: 10.1111/bjet.13145.
19. L. L. Shiau Gee, J. Dolah, and V. B. Pangayan, "Visual Preferences for Educational Game Designs Through the Graphic Style Approaches," J. Gendang Alam, no. January, 2019, doi: 10.51200/ga.v0i0.2181.
20. Y. Fan, D. K. Chong, and Y. Li, "Beyond play: a comparative study of multi-sensory and traditional toys in child education," Front. Educ., vol. 9, no. March, pp. 1–11, 2024, doi: 10.3389/feduc.2024.1182660.
21. C. O. Amaefule, J. Breitwieser, D. Biedermann, L. Nobbe, H. Drachsler, and G. Brod, "Fostering children's acceptance of educational apps: The importance of designing enjoyable learning activities," Br. J. Educ. Technol., vol. 54, no. 5, pp. 1351–1372, 2023, doi: 10.1111/bjet.13314.