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MIXED-METHODS OF USER EXPERIENCE EVALUATION OF EDUCATIONAL BOARD GAMES DESIGNED WITH 3D PRINTINGTECHNOLOGY

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ABSTRACT

Purpose: *The study aimed to evaluate Adventure Seekers, an educational board game designed with the support of 3D printing and artificial intelligence–assisted prototyping tools. Its primary goal was to assess how children experience the game cognitively, emotionally, and socially, and to determine how AI-supported design can enhance inclusivity and engagement in game-based learning.*

Need for the study: *Although board games are widely recognized as effective educational tools, few studies have examined how user experience (UX) evaluation and AI-assisted design processes influence children's learning engagement. By integrating UX assessment with AI-driven prototyping, this research addresses the growing need for inclusive, data-informed, and technologically enhanced learning environments.*

Methodology: *A mixed-methods approach was employed, combining post-game surveys (quantitative data) with in-situ and post-session interviews (qualitative data). The study involved 81 participants aged 10–13, tested in real-world educational settings such as schools and scouting centers. Game components were modeled with Meshy.ai and ChatGPT to accelerate prototyping and adapt designs based on user feedback.*

Findings: *The results indicate a highly positive user experience. Ninety-three percent of participants found the game visually appealing, 88% rated the rules as easy to understand, and 90% expressed a willingness to play again. Statistical analysis (Cronbach's $\alpha = 0.87$; logistic regression $R^2 = 0.42$) showed that visual appeal and curiosity were the strongest predictors of replay intention. Interview data confirmed strong emotional engagement, cooperation, and enjoyment, with minor improvement suggestions related to component size and game variety.*

Practical Implications: *The study demonstrates that combining 3D printing and AI-assisted design supports faster iteration, personalization, and inclusive usability in educational games. It also provides a methodological model for integrating UX research into the development of pedagogical tools. These findings highlight how AI can function as a creative partner in designing learning materials that are not only functional but emotionally resonant and engaging for young learners.*

Keywords: Educational board games, User Experience (UX), 3D printing, Mixed-methods research, Game-based learning, Cognitive development, AI in 3D design process

Jel codes: A29, O33, C93

1. INTRODUCTION

Modern education increasingly turns toward engaging, experience-based methods that respond to the cognitive and emotional diversity of learners. Among such approaches, board games stand out as particularly effective tools that merge entertainment with learning. They foster not only knowledge acquisition but also executive functions such as planning, inhibition, and cognitive flexibility (Diamond 2013). Moreover, research has consistently shown that gameplay stimulates linguistic, mathematical, and social competencies while creating a cooperative atmosphere conducive to emotional development (Prensky 2001; Gee 2004). In both school and out-of-school contexts, educational games have thus become a bridge between structured learning and playful exploration – a space where motivation, curiosity, and challenge naturally coexist.

Recent technological advances – especially in additive manufacturing and artificial intelligence–assisted design – have opened new opportunities for personalized learning tools. 3D printing allows educators and designers to produce physical components tailored to children's needs, including those with sensory or motor challenges (Pantazis and Priavolou 2017; Kwon et al. 2020; Jorge et al. 2021). When paired with AI-based design support systems such as Meshy.ai or text-driven modeling tools, it becomes possible to iterate prototypes rapidly and adjust them according to user feedback. By combining ergonomics, aesthetics, and safety, these technologies extend accessibility and usability while nurturing creativity among young learners.

Parallel to these technological shifts, education research increasingly emphasizes user-centered design—commonly referred to as User Experience (UX). In game-based learning, UX evaluation goes beyond verifying knowledge outcomes; it examines how aesthetic pleasure, emotional engagement, and functional fluency influence cognitive effort and motivation (Norman 2013; Kim and Pekrun 2014). Emotions play a vital role in learning: positive affect supports curiosity and persistence, while frustration, when balanced, fosters resilience (Immordino-Yang and Damasio 2007). For this reason, understanding how young players perceive and feel the game – both during and after play – is essential for designing truly inclusive and effective educational experiences.

The present study aimed to conduct a multidimensional evaluation of *Adventure Seekers*, an educational board game developed through a design process integrating 3D printing and AI-assisted modeling tools. The evaluation focused on how children aged 10–13 perceived and interacted with the game within authentic educational contexts – scouting meetings and school activities. A mixed-methods design was applied, combining quantitative measures (post-game surveys) with qualitative exploration (in-situ and retrospective interviews). This combination made it possible to capture both numerical patterns and nuanced interpretations of player experience, including aesthetic appreciation, emotional engagement, ergonomic comfort, and perceived educational value (Morville 2004; Vermeeren et al. 2010).

2. LITERATURE REVIEW

Modern pedagogy increasingly embraces active learning methods that encourage students to become co-creators of knowledge rather than passive recipients. Board games fit naturally into this constructivist paradigm, as they combine play, exploration, and social interaction – key components of experiential learning. Dewey's concept of *learning by doing* (Dewey 1938) underscores that knowledge arises from meaningful experience, while Piaget and Vygotsky (Vygotsky 1980; Piaget 1999; Ültanır 2012) emphasized the importance of social dialogue and hands-on discovery in cognitive growth. These ideas remain central to game-based learning today, where play becomes a structured yet flexible framework for building understanding through participation, collaboration, and reflection.

Empirical research confirms that regular engagement with board games enhances key executive functions – cognitive control, planning, and mental flexibility – by placing learners in situations that demand rapid decision-making and adaptive thinking (Diamond 2013). Structured gameplay also reinforces mathematical reasoning, language skills, and logical problem-solving (Sarı and Szczygieł 2023). Beyond cognition, the social dimension of games cultivates empathy, cooperation, and fairness, helping children learn to navigate competition, handle setbacks, and celebrate collective success. Such emotional and interpersonal learning outcomes make board games especially valuable in both inclusive and mainstream education contexts (Garris et al. 2002).

From a didactic perspective, educational board games perform several interconnected functions – motivational, diagnostic, and reinforcing. Their interactive nature sustains learner engagement and curiosity, while also offering teachers a unique observational window into students' problem-solving approaches and group dynamics. When used thoughtfully, games become informal yet powerful assessment tools, revealing both strengths and areas for further development (Alotaibi 2024). This dual role – as both learning medium and diagnostic instrument – illustrates why games are increasingly seen not merely as entertainment but as structured learning environments that generate authentic data about cognitive and social processes (Hamari et al. 2016).

Games also hold diagnostic potential by reproducing real-world decision-making within a safe, low-pressure environment (Howard-Jones and Demetriou 2008). They enable educators to observe how learners plan, negotiate, and adapt – behaviors that reveal individual cognitive styles and social strategies. Such contexts allow informal yet meaningful assessment of both academic progress and interpersonal skills. Moreover, repetition and feedback loops embedded in gameplay support knowledge consolidation without inducing test-related anxiety (Howard-Jones and Demetriou 2008; Ilić Rajković et al. 2020; Sun et al. 2023). In this sense, games act as living laboratories for studying learning in action.

Because of their inherently social structure, board games promote cooperation, negotiation, and perspective-taking – skills that directly contribute to prosocial behavior and empathy (Papoutsi and Drigas 2016; Stubbs and Sorensen 2025). The cooperative or semi-competitive format also encourages students to communicate effectively and appreciate diverse viewpoints. These characteristics make educational board games highly compatible with inclusive teaching practices, providing a shared space where learners with different abilities can participate meaningfully and learn from one another

Within inclusive education, board games offer remarkable flexibility. Their modular structure and adjustable difficulty levels allow learners with disabilities to engage at an appropriate pace while still participating fully in group activities. Such inclusiveness reduces social distance, normalizes diversity, and reinforces the sense of belonging (Cezarotto et al. 2022; Cezarotto and Armstrong 2023). Because the motivation arises from play rather than obligation, students are more likely to stay engaged and retain what they learn. This combination of accessibility, autonomy, and motivation positions games as powerful instruments for inclusive pedagogy.

From a design standpoint, an educational board game evolves through three complementary phases: defining goals, constructing the system of play, and evaluating user experience (Salen Tekinbaş 2011). For the game to be pedagogically effective, each phase must correspond to the learner's perceptual, cognitive, and motor capacities. Personalization plays a key role in this alignment. The introduction of 3D printing and AI-assisted design tools has expanded what can be customized—from component size and texture to ergonomics and symbolic meaning. This integration allows designers to create inclusive learning environments where visual, tactile, and functional accessibility are embedded directly into the design process (Bicer et al. 2017; Jorge et al. 2021).

3D-printed components can be readily adjusted in size, texture, or form, which enhances both usability and aesthetic appeal. Beyond practical benefits, the process itself encourages creativity and iterative thinking – learners and designers alike engage in cycles of testing, reflection, and refinement (Bicer et al., 2017; Kwon et al., 2020). In educational settings, this mindset aligns closely with constructivist and design-thinking approaches, where making becomes a way of understanding.

3. METHODOLOGY

3.1. Aim of the study

The main goal of this study was to conduct a multidimensional user experience (UX) evaluation of Adventure Seekers – an educational board game developed through a design process that integrated 3D printing and AI-assisted prototyping. The research aimed to assess how children perceived the game's visual appeal, usability, and educational relevance in authentic learning environments. Equal emphasis was placed on subjective impressions and measurable indicators of engagement.

The methodological foundation of the study followed a mixed-methods approach, combining quantitative tools (a structured post-game survey) with qualitative methods (semi-structured in-game and post-game interviews)(Bernstein and Nunnaly 1995; Johnson and Onwuegbuzie 2004; Bryman

2006; Creswell et al. 2018). This combination allowed for both statistical comparison and interpretative depth.

The study also sought to identify which design features required further optimization and how AI-supported design and 3D printing could enhance inclusivity and personalization in educational game development. The 3D elements – such as pawns, tokens, and tiles – were generated using Meshy.ai, an artificial intelligence platform that produces 3D models from textual and visual prompts. Generated models – The generated models were checked and, where necessary, corrected in the Blender modelling program. Early concept descriptions were refined with ChatGPT, enabling iterative improvements to rules and component ergonomics. Physical prototypes were printed using a Prusa MK4 with PLA filament, chosen for its safety, low environmental footprint, and tactile comfort suitable for younger players.

3.2. Participants

The study included 81 participants aged 10–13 years. This age range aligns with the educational framework of the Polish Scouting Association - ZHP (2009; Bronfenbrenner 2009; Czechowska et al. 2014), where structured play and cooperation-based tasks are central elements of pedagogical practice (Kwon et al., 2020). Participants were recruited from scouting groups and partner schools that regularly incorporate board games into educational activities. Conducting the study in these familiar settings ensured ecological validity and reduced experimental stress(Bronfenbrenner 2009; Cohen 2018).

In accordance with the "small group" system used in scouting, participants played in teams of six. The sample was predominantly female (74%, n = 60), with 13 boys (16%) and 8 participants (10%) who preferred not to disclose gender. While the sample provided valuable insights into this demographic, it was not intended to represent the entire school-age population. Instead, the focus was on exploring authentic user experiences within a specific and naturally cohesive educational community.

All participants took part voluntarily, with informed consent obtained from parents or legal guardians. Data were collected anonymously, following institutional ethical guidelines.

3.3. Research methods and tools

A mixed-methods design was adopted, combining quantitative and qualitative approaches to achieve both breadth and depth of analysis. Three complementary tools were used:

- Post-game survey – to quantify player satisfaction and evaluate key UX dimensions (aesthetics, ergonomics, comprehensibility, and emotional engagement).
- In-game interviews – short moderator-led interactions during gameplay to capture spontaneous impressions and behaviors.
- Post-game interviews – semi-structured individual or small-group discussions to collect reflective feedback after play sessions.

The survey contained 18 items: 12 closed-ended Likert-scale statements (1 = strongly disagree, 5 = strongly agree), 4 single-choice questions, and 2 open-ended questions. Example items included:

- "The rules were clear and easy to remember."
- "The 3D-printed pieces were comfortable to handle."
- "I felt excited while playing the game."

The structure of the questionnaire was inspired by UX research frameworks (Morville 2004; Vermeeren et al. 2010; DeVellis 2017; Lazar and Feng 2017) and adapted to children's cognitive and linguistic abilities. Open-ended questions allowed participants to elaborate freely, offering insights that complemented the quantitative data.

3.4. Research process

The study was carried out in natural learning environments – schools and scouting centers – where participants regularly engaged in cooperative tasks. This choice ensured ecological validity and authentic social interaction. The procedure consisted of three stages(Nicolini 2013; Cohen 2018; Patton 2025):

- Introduction and briefing. Participants were introduced to the research aims and trained in the game rules through a short demonstration.

- Gameplay and in-situ interviews. Children played Adventure Seekers in teams of six, while the facilitator observed behaviors and conducted brief, non-intrusive interviews to record immediate reactions.
- Post-game debriefing. After gameplay, participants completed the questionnaire and took part in follow-up interviews focusing on overall impressions, emotions, and perceived educational value.

Sessions were conducted in familiar, friendly settings typical for scouting meetings – shared tables, group discussions, background chatter. This everyday atmosphere encouraged authentic behavior and emotional expression, minimizing performance bias often seen in formal classroom experiments.

3.5. Technologies and materials used

All physical components were produced using a Prusa MK4 3D printer and PLA filament – a material known for durability, safety, and environmental friendliness. The design prioritized child ergonomics: pieces were proportioned for small hands, with rounded edges to enhance comfort and safety.

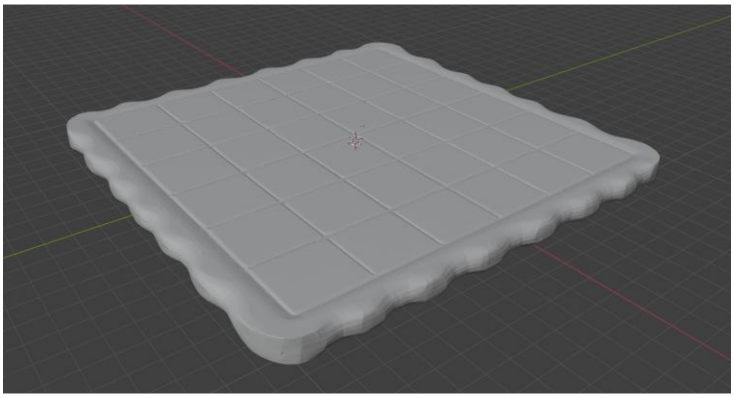

Figure 1. Photo of the game board model used in the game. Screenshot from Blender.
Source: own elaboration

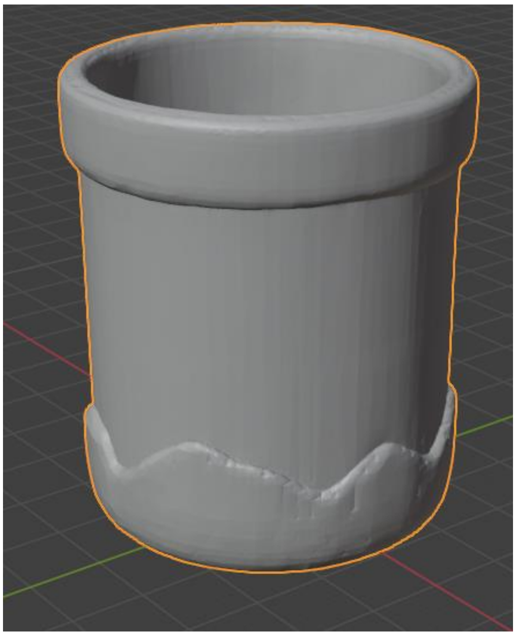

Figure 2. Photo of the basket model for other figurines used in the game. Screenshot from Blender.
Source: own elaboration

Figure 3. Photo of the board game used in the study during gameplay.
Source: own elaboration

Artificial intelligence tools supported the iterative design process. Meshy.ai was used to generate 3D component concepts from textual descriptions and sketches, while ChatGPT assisted in rewording and refining game instructions to match the cognitive level of younger users. This AI-supported workflow accelerated prototyping and made it easier to incorporate real user feedback after each testing phase (Poleac 2024; Olmanson et al. 2025). Through this combination of AI assistance and physical prototyping, the development process mirrored modern iterative UX design cycles, bridging technology, pedagogy, and creativity.

4. RESULTS

4.1. Survey results

The results indicate that Adventure Seekers was enthusiastically received by the participants. Both quantitative data and qualitative remarks suggest that the game effectively fulfilled its dual purpose—as an educational tool and a playful, emotionally engaging activity.

Aesthetic and ergonomic appeal. A large majority of players (93%) found the game visually attractive, highlighting the colorful board and tactile 3D-printed pieces. Almost all respondents (95%) described the components as durable and pleasant to handle. Three out of four participants (74%) noted that the shapes and colors improved clarity and made it easier to follow the gameplay. One 12-year-old girl said, “I liked that every token had a different shape – it helped me remember what was mine.”

Rule clarity and gameplay dynamics. Most players (88%) reported that the rules were easy to understand, and 91% said that learning them took only a few minutes. The gameplay was described as interesting by 89% of respondents, although some mentioned that sessions lasting over 40 minutes could become repetitive.

Usability and component design. About 77% of players found the pieces comfortable to move and the board easy to navigate. Around one-fourth suggested small improvements, such as enlarging the pawns or slightly extending the play area. A 10-year-old participant commented, “Sometimes the pieces bumped into each other – we could make the board a bit bigger.”

Overall experience and motivation to replay. Ninety percent of respondents expressed willingness to play again, describing the game as cooperative and exciting. Children frequently emphasized the balance between competition and teamwork, noting that the group tasks created a sense of fairness. One boy (age 11) summarized: “It felt fair because everyone had a turn to do something important.”

Statistical validation. The internal consistency of the questionnaire was assessed using Cronbach’s alpha, which reached $\alpha = 0.87$, indicating high reliability (Nunnally & Bernstein, 1994). The coefficient was based on 12 Likert-scale items covering aesthetics, ergonomics, clarity of rules, and emotional response.

A Mann–Whitney U test was conducted to compare responses between genders, accounting for unequal sample sizes. None of the differences were statistically significant (all $p > 0.05$), though a small effect size was observed for visual preference ($r = 0.18$).

A binary logistic regression model was used to identify predictors of willingness to replay the game. The strongest predictor was visual appeal ($\beta = 1.38$, OR = 3.97, $p = .01$), followed by gameplay curiosity ($\beta = 0.52$, OR = 1.68, $p = .04$) and ease of rule comprehension ($\beta = 0.33$, OR = 1.40, $p = .05$). Model fit was satisfactory (Nagelkerke $R^2 = 0.42$), and no multicollinearity was detected (all VIF < 2). These findings indicate that positive aesthetic impressions and intellectual curiosity were the most influential factors motivating replay intentions.

Collectively, the results show that children valued Adventure Seekers for its vivid aesthetics, clear rules, and cooperative nature. While a few ergonomic adjustments were suggested, the overall UX indicators confirm that the game achieved a strong balance between enjoyment and educational value.

4.2. Interviews

The qualitative interviews complemented the survey results, offering a deeper understanding of how children experienced *Adventure Seekers* emotionally and socially.

Aesthetics and craftsmanship. Across almost all groups, participants praised the bright colors and fine details of the board and tokens. As one 11-year-old girl explained, *“It looks like something you’d buy in a real store, not something made in class.”* A few children mentioned minor imperfections, such as uneven paint or small scratches on the pawns, but these remarks were isolated.

Usability and clarity. Most participants found the pieces easy to hold and move, and the instructions clear. Out of 14 groups, 13 reported no issues in understanding the rules. Observations during play showed that children quickly internalized the game flow and helped peers who were less confident.

Emotional engagement. Nine groups explicitly expressed excitement or curiosity during play. A 12-year-old boy noted, *“I like that we don’t just answer questions—we have to think together.”* Another participant added, *“It’s fun when something unexpected happens, like a surprise card.”* Such reactions illustrate how design elements that balance challenge and reward sustain motivation and collective focus.

Perceived fairness and willingness to replay. All groups described the game as fair, emphasizing that each player had meaningful participation. Nearly every group (14/14) expressed enthusiasm to play again. One facilitator observed, *“Children immediately asked if we could keep the game for next week.”* This strong replay intention aligns with the quantitative findings, reinforcing that perceived fairness and aesthetic appeal contribute significantly to overall satisfaction.

Suggestions for improvement. In six groups, children suggested enlarging certain components or adding new challenge cards to make future rounds more varied. Rather than expressing dissatisfaction, these suggestions reflected engagement and ownership—the players were already imagining how the game could evolve.

5. CONCLUSSIONS

The findings of this study demonstrate that Adventure Seekers – an educational board game designed through the combined use of 3D printing and AI-supported prototyping – offers considerable educational and experiential value for children aged 10–13. By integrating post-game surveys with in-situ and retrospective interviews, the research captured not only what children thought about the game but also how they felt while playing it. This emotional and cognitive duality is central to understanding how playful learning environments shape motivation, cooperation, and memory.

Participants consistently emphasized the aesthetic appeal, clarity of rules, and cooperative nature of the game. The 3D-printed components were described as durable and satisfying to handle, while the visual design encouraged engagement from the start. Importantly, the clear mechanics reduced cognitive overload, allowing children to focus on collaboration and problem-solving – skills directly linked to executive functioning and socio-emotional learning.

Several constructive suggestions emerged. Some children proposed larger pieces for better visibility, while others wanted more diverse challenge cards or multiple difficulty levels. These comments, while minor, reflected genuine engagement and ownership – traits that indicate intrinsic motivation and long-term learning potential.

The integration of AI tools such as Meshy.ai and ChatGPT proved especially beneficial during the prototyping phase. Meshy.ai allowed rapid generation and scaling of component models, while ChatGPT was used to refine rule explanations and adjust language for younger audiences. This workflow reduced design time and supported a more iterative, user-centered process – demonstrating how AI can complement human creativity rather than replace it. Such hybrid workflows exemplify the emerging paradigm of AI-augmented design thinking in education.

A key strength of this study lies in its ecological validity. Conducting tests in natural learning environments – schools and scouting centers – allowed participants to behave spontaneously and provided authentic feedback rooted in real social contexts. However, this also introduces limitations: the sample, while adequate for exploratory analysis, was not representative of the broader population, being limited to a specific cultural and organizational context (ZHP). Future studies could expand the sample to different age groups, school systems, and cross-cultural settings to explore how context influences gameplay experience and educational outcomes.

Overall, Adventure Seekers illustrates how thoughtful integration of UX research, AI-assisted design, and 3D printing can produce educational tools that are inclusive, customizable, and deeply engaging. Beyond its immediate application, the study demonstrates the methodological value of mixed-methods research for evaluating play-based learning experiences. Future iterations of the game will continue this approach, using user data and AI-assisted prototyping to refine design features and explore new dimensions of engagement and learning.

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