

Labyrinth of Traps: Development and Evaluation of a 2D/3D Digital Game for Teaching Spatial Orientation

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Abstract. *This paper introduces Labyrinth of Traps, an educational game designed to support the teaching of spatial thinking and cartographic literacy through immersive gameplay. The artifact features six progressive levels that challenge students to transition from 2D allocentric perspectives to 3D egocentric environments with restricted visibility. The game integrates core navigation concepts, including GPS logic, compass orientation, map decoding, celestial navigation, and radar proximity. The research followed an empirical methodology, evaluating the tool with 31 participants through quantitative and qualitative measures. Descriptive results indicated high levels of engagement, with responses concentrated in the upper range of the Likert scale. Inferential analysis was conducted using the nonparametric Wilcoxon test to assess whether participants' evaluations were significantly greater than the neutral value. The results showed that key dimensions related to usability and learning were significantly above the baseline, indicating a consistent tendency toward agreement. Additionally, most participants reported increased confidence in using spatial orientation tools after interacting with the game. These findings indicate that participants perceived the proposed approach as useful for supporting the learning of spatial navigation concepts and reducing the abstraction typically associated with cartographic education.*

Keywords: *Spatial Thinking, Cartographic Literacy, Serious Games, Geographic Learning, Spatial Orientation.*

1. Introduction

Geography and Cartography are essential disciplines for understanding space and society. However, teaching concepts such as coordinates, cardinal directions, and navigation tools remains challenging due to their abstract nature. As argued by [Almeida and Passini 1989], cartographic literacy should go beyond memorizing symbols and instead promote the ability to interpret and mentally represent space. Difficulties in visualizing how instruments such as compasses operate or how navigation by stars occurs create barriers that demand more interactive and experiential learning approaches.

This work presents and evaluates Labyrinth of Traps (*Labirinto das Armadilhas*), a digital educational game designed to provide opportunities for practicing spatial orientation concepts through progressive challenges in both 2D and 3D environments. The pedagogical approach emphasizes functionality: players must understand and apply concepts such as direction, proximity, and spatial reference in order to progress in the game.

Thus, encourages learners to engage actively with spatial concepts rather than passive instruction.

The study adopts an empirical methodology, in which the game was evaluated with 31 participants through a structured questionnaire using Likert-scale items (from very poor to very good) for the main issues of interest to the work. Given the ordinal nature of the collected data, the analysis combines descriptive statistics with nonparametric inferential methods. In particular, it was employed to assess whether participants' responses were significantly above the neutral baseline, providing statistical evidence of perceived usability and learning.

In this context, the concept of Spatial Thinking becomes central. According to [Council 2005], spatial thinking involves a set of cognitive skills that enable individuals to structure problems, derive solutions, and communicate ideas based on spatial relationships. In *Labyrinth of Traps*, these skills are stimulated through the transition between two fundamental frames of reference: allocentric and egocentric.

The allocentric perspective, predominant in the 2D levels, requires players to interpret spatial relationships from an external viewpoint, similar to reading a map. In contrast, the egocentric perspective, explored in the 3D levels, places the player at the center of perception, requiring continuous transformation of abstract spatial information into concrete navigation decisions. This transition reflects the process described by [Tuan 2013], in which abstract space becomes meaningful through experience.

The use of digital games as mediating tools is supported by [Vygotsky 2007], who highlights the role of instruments in extending the learner's zone of proximal development. Additionally, [Prensky 2001] argues that interactive environments aligned with digital culture foster engagement and active learning, especially when errors are treated as part of the learning process.

The remainder of this paper is organized as follows: Section 2 presents the theoretical framework; Section 3 discusses related work; Section 4 describes the methodology; Section 5 presents and analyzes the results; and Section 6 concludes the paper with final considerations and future directions.

2. Theoretical Framework

Recent studies reinforce the effectiveness of digital environments for developing spatial skills. [Yadollahi et al. 2022] highlight the importance of perspective-taking in spatial learning through interactive environments. The study by [Slattery et al. 2024] shows that structured interventions using *Minecraft Education* significantly improve spatial reasoning, although their open-ended nature may limit pedagogical control. Similarly, [Hussain and Khan 2024] demonstrate that immersive virtual reality enhances spatial cognition and engagement, albeit requiring specialized hardware. In contrast, this work adopts a controlled progression of challenges, integrating multiple spatial tools in accessible 2D and 3D environments, explicitly training transitions between representations.

Spatial Thinking involves the integration of spatial concepts, representation tools, and reasoning processes [Council 2005]. It is essential for interpreting maps and navigating environments and can be significantly improved through targeted inter-

ventions [Uttal et al. 2013]. In educational contexts, it must be explicitly addressed [Jo and Bednarz 2009], particularly in cartographic literacy, which requires the ability to interpret and mentally represent space rather than merely memorizing symbols [Almeida and Passini 1989].

Furthermore, spatial understanding is inherently experiential. As argued by [Tuan 2013], space becomes meaningful when transformed into place through interaction, reinforcing the need for active learning environments in which learners engage directly with spatial challenges.

Digital games provide interactive environments that are intended to support learning through experimentation and problem-solving [Gee 2003]. They also bridge formal education and digital culture, promoting active participation [Squire 2011]. Empirical evidence indicates that serious games have been reported to improve cognitive outcomes and engagement when aligned with clear pedagogical objectives [Connolly et al. 2012].

Additionally, games offer immediate feedback, clear goals, and resilience to failure, elements that enhance motivation and learning [McGonigal 2011]. These characteristics make them particularly suitable for addressing abstract concepts such as spatial orientation, where traditional instruction often lacks concreteness.

Spatial cognition involves different frames of reference. Allocentric representations (maps) require understanding spatial relations from an external viewpoint, while egocentric navigation is based on the individual's perspective [Montello 1993]. Humans construct cognitive maps through interaction and experience [Tversky 1993], yet translating between representations remains a significant challenge in educational contexts [Ishikawa 2016].

This work proposes an educational environment intended to address this challenge by designing learning experiences that explicitly require transitions between allocentric and egocentric perspectives, supported by structured gameplay mechanics and progressive difficulty. Finally, from an evaluation perspective, this study adopts an ordinal interpretation of user responses collected through Likert-scale items. Rather than assuming interval properties, the analysis respects the ordered nature of the data, employing nonparametric methods such as the Wilcoxon signed-rank test to assess whether observed responses reflect a statistically significant tendency toward agreement.

3. Related Games and Educational Works

The design of Labyrinth of Traps was informed by both commercial digital games and academic studies related to spatial learning and educational game design.

Classic maze-based games such as [Namco 1980] establish fundamental navigation mechanics, including pathfinding, obstacle avoidance, and spatial awareness. However, these games primarily emphasize reflex-based interaction and full environmental visibility, lacking explicit educational objectives or structured cognitive progression.

Sandbox environments such as [Mojang Studios 2011] demonstrate the potential of open-ended 3D exploration for developing spatial reasoning. While highly effective in fostering creativity and autonomy, their lack of pedagogical constraints may limit their applicability in formal educational settings, where guided learning and measurable outcomes are required.

Task-oriented multiplayer games like [Innersloth 2018] introduce spatial reasoning through map-based navigation and memory, requiring players to interpret static representations and recall spatial layouts. Similarly, [Niantic 2016] highlights the relevance of real-world navigation tools, although its dependence on physical movement and GPS data reduces controllability in classroom environments.

From an academic perspective, [Garozi et al. 2021] explores maze-based learning for formal grammars, demonstrating the effectiveness of structured challenges for abstract reasoning, albeit in a different domain. Additionally, [Rizzatti et al. 2021] supports the use of digital games in cartographic literacy, particularly emphasizing the interpretation of visual representations.

Despite these contributions, existing works tend to address spatial learning through isolated dimensions, such as exploration, memory, or interaction. Few approaches explicitly integrate multiple navigation tools while also requiring continuous transitions between allocentric (map-based) and egocentric (first-person) representations.

In contrast, Labyrinth of Traps proposes a controlled progression of challenges that combines 2D and 3D environments, integrates multiple spatial orientation tools (e.g., compass, maps, radar, and celestial references), and systematically increases cognitive demand. This design was designed to encourage the practice of spatial thinking, directly targeting the difficulties associated with transforming abstract spatial representations into actionable navigation decisions.

Furthermore, unlike open-ended or purely exploratory systems, the proposed approach allows for structured evaluation through ordinal user feedback, analyzed using nonparametric statistical methods. This strengthens the empirical grounding of the study by aligning the design of the educational artifact with a consistent and appropriate evaluation methodology.

4. Methodology

This work adopted a quantitative, exploratory, cross-sectional research design aimed at investigating participants' perceptions regarding the educational potential, usability, and engagement promoted by the proposed game. The study comprised three main stages: (i) design and development of the educational game, (ii) data collection through a structured questionnaire, and (iii) statistical analysis of user responses.

4.1. Game Design and Development

The development of Labyrinth of Traps followed an iterative design process guided by pedagogical objectives related to spatial orientation. The game was structured into six progressive levels, each introducing specific navigation concepts while gradually increasing cognitive and perceptual complexity. The application's original implementation was done in C++ using the OpenGL graphics library [Hussain 2018].

The initial levels (2D) focus on fundamental spatial skills, including route following (GPS), directional orientation (compass), and map interpretation without positional feedback. The later levels (3D) introduce immersive challenges such as celestial navigation, limited visibility, resource management, and proximity-based decision-making through radar systems.

Core design elements include progressive difficulty aligned with learning objectives, integration of navigation tools (GPS, compass, map, stars, radar), environmental constraints (fog, darkness, restricted visibility), and immediate feedback mechanisms (rewards, penalties, visual cues). This structure ensures that spatial reasoning is actively required for successful gameplay. The educational artifact was designed according to principles of progressive learning, in which increasingly complex navigation tasks require players to apply different spatial orientation strategies.

4.2. Data Collection Instrument

Data were collected through a structured questionnaire administered via Google Forms platform after participants completed all game levels. The sample consisted of 31 participants represented different levels of familiarity with digital games, ranging from occasional to frequent players, allowing the evaluation of the proposed educational game across heterogeneous user profiles. To be included in the study, participants were required to complete all six game levels before answering the evaluation questionnaire. No participant received financial compensation for participating in the study.

Participation was entirely voluntary, and all participants were informed about the objectives of the research, the study procedures, and the anonymous treatment of the collected data before completing the experiment. No personally identifiable information was collected, and participants were free to withdraw from the study at any time without any penalty. The collected data were used exclusively for research purposes and analyzed in aggregated form to preserve participant confidentiality. The instrument was composed of three sections:

(i) Participant Characteristics: Questions on gender, age group, and frequency of video game usage were included to characterize the sample.

(ii) Game Experience and Usability: Participants evaluated aspects such as overall experience when playing the game, clarity of instructions, relevance of the challenges proposed at each level, how the interactions with simulations of the tools occurred, and the quality of game feedback. These items were measured using a 5-point Likert scale that describe the feel of the gameplay experience, ranging from 1 to 5 (1 – very poor; 2 – poor; 3 – neutral; 4 – good; 5 – very good), which is suitable for ordinal statistical analysis. These questions are considered the most important in the study and, therefore, will be analyzed using the non-parametric Wilcoxon signed-rank test [Gibbons 1993] to assess whether participants positively evaluated their game experience. Because Likert responses represent ordered categories rather than interval measurements, nonparametric methods are generally recommended for inferential analyses.

(iii) Perceived Educational Value and Educational Potential: Participants rated (Low, Neutral, or High) the extent to which the game elements (animations, graphics, music, and sound effects) contributed to the understanding of spatial navigation tools (e.g., compass, GPS, radar) and whether they would recommend their use in a classroom context.

4.3. Statistical Analysis

The collected data were analyzed using both descriptive and inferential statistical methods, respecting the ordinal nature of Likert-scale responses.

Descriptive statistics included median, interquartile range, mean, and standard deviation, providing an overview of central tendency and variability. Although means are reported for completeness, medians are emphasized as the most appropriate measure for ordinal data.

For inferential analysis, each Likert item was examined independently using the Wilcoxon signed-rank test, a nonparametric method suitable for one-sample ordinal data. The test was applied to evaluate whether the median response was significantly greater than the neutral value (3), using a one-tailed hypothesis ($H_0 : median = 3; H_1 : median > 3$). A significance level of 0.05 was adopted. In addition to p-values, effect sizes were calculated using the r statistic ($r = Z/\sqrt{N}$, where Z is the standardized statistic and N is the effective sample size), allowing the assessment of practical significance [Gibbons 1993]. Since the questionnaire items represent distinct constructs and the analyses are exploratory, no correction for multiple comparisons was applied.

The remaining categorical variables were analyzed using frequency distribution and examined using exploratory analysis to identify recurring themes related to usability, engagement, and perceived learning.

5. Results and Discussion

Some scenes extracted from the game are shown in Figure 1. The Portuguese interfaces describe the main menu (Fig. 1a), level selection (Fig. 1b), a 2D level where the character is guided by compass (Fig. 1c) and another by GPS (Fig. 1d), a 3D labyrinth level (Fig. 1e), as well as game instructions (Fig. 1f). During the game, the character must be guided by a navigational instrument along a path filled with obstacles. The player wins by reaching the destination while avoiding environmental hazards. Failure occurs when all available lives are lost due to collisions, burns, falls, or other obstacles.

The following subsections present the statistical analysis of the collected data, combining descriptive and inferential approaches, consistent with the ordinal nature of the responses, followed by an interpretation based on the theoretical framework.

5.1. Participant Characteristics

The study included 31 participants, predominantly male (67.7%) (Fig. 3a), with a median age of 22 years (Fig. 4b). The inclusion of both frequent and infrequent gamers allowed the evaluation of the game across heterogeneous user profiles, increasing the ecological validity of the findings (Fig. 3c).

5.2. Analysis of Experience and Usability

Table 1 presents descriptive statistics for the evaluated items. As expected for ordinal data, medians provide the most appropriate measure of central tendency. Responses are clearly concentrated in the upper range of the scale, with median values equal to or above 4 for all items. In particular, Overall Experience, Interaction with Tool Simulations, and Game Feedback reached the maximum median (5), indicating a strong positive perception.

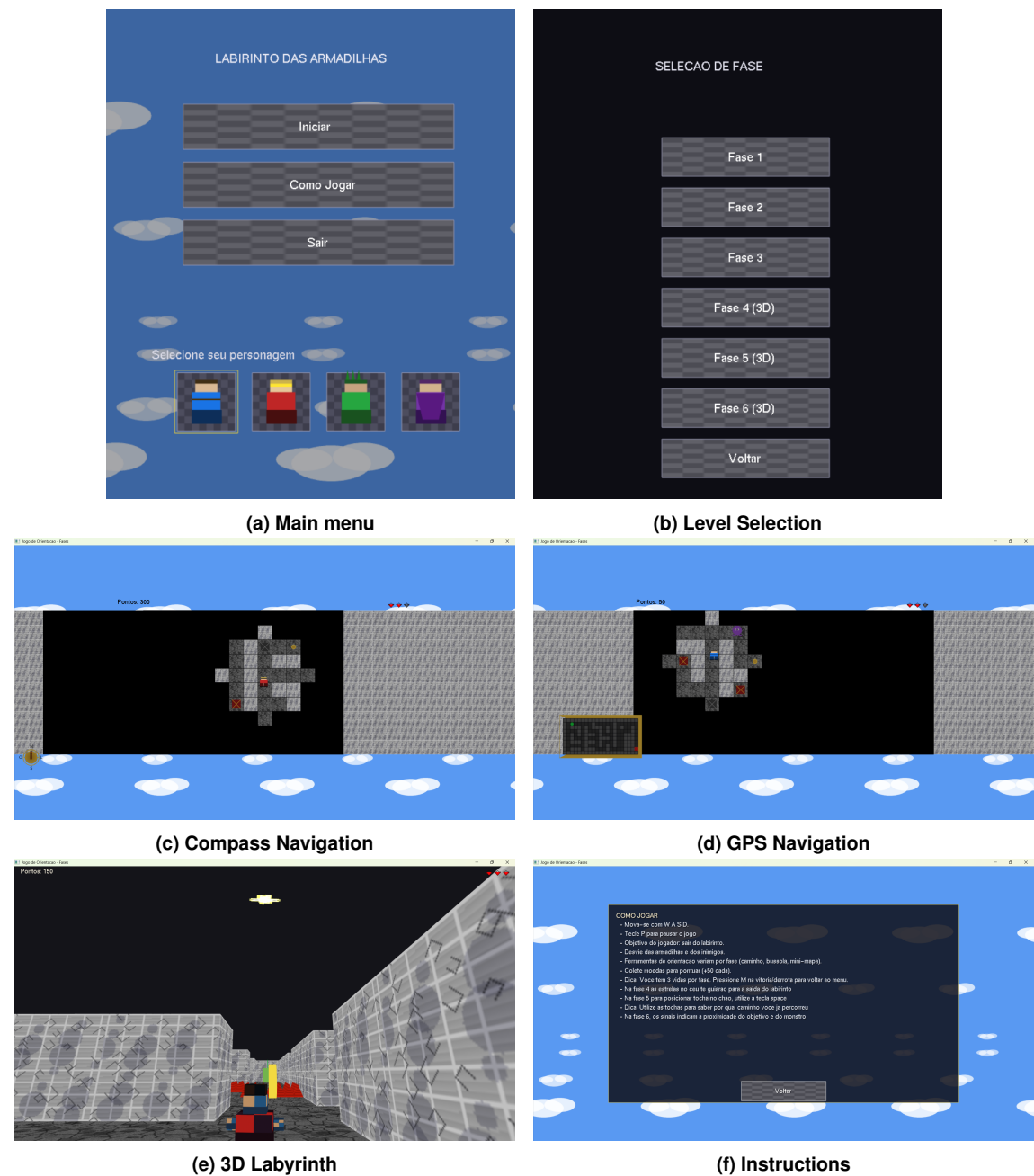


Figure 1. Scenes from the game Labyrinth of Traps.

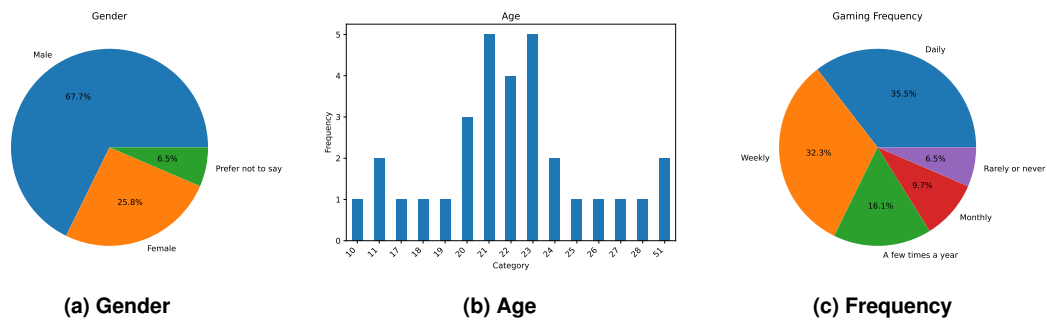


Figure 2. Participant Characteristics.

Table 2. Wilcoxon Signed-Rank Test Results ($H_1 : median > 3$)

Item	Median	p-value	r
Overall Experience	5	1.86e-09	1.00
Clarity of Instructions	4	5.96e-07	0.97
Relevance of the Proposed Challenges	4	1.49e-08	1.00
Interaction with Tool Simulations	5	2.98e-08	1.00
Game Feedback	5	2.09e-07	0.97

Table 1. Descriptive Statistics of Game Evaluation (Likert Scale 1–5)

Evaluated Criterion	Median	IQR	Mean	Std. Dev.
Overall Experience	5	1.00	4.65	0.61
Clarity of Instructions	4	1.50	4.19	0.91
Relevance of the Proposed Challenges	4	1.00	4.32	0.75
Interaction with Tool Simulations	5	1.00	4.39	0.80
Game Feedback	5	1.00	4.29	0.86

To determine whether these evaluations significantly exceed the neutral baseline, each item was analyzed using the Wilcoxon signed-rank test (one-tailed, $H_1 : median > 3$) (Table 2). All items presented p-values far below the 0.05 threshold, providing strong statistical evidence that participants' evaluations are significantly above neutrality. Effect sizes were consistently large ($r > 0.5$), indicating that these differences are not only statistically significant but also practically meaningful. The magnitude of the observed effects suggests a robust and consistent tendency toward agreement across all evaluated dimensions.

5.3. Experience Modalities: Visual vs. Auditory

As illustrated in Figure 3, visual elements were rated substantially higher than auditory components. This finding aligns with the inherently visual nature of spatial cognition, which relies on graphical representations such as maps and environmental cues.

5.4. Perceived Educational Value and Confidence

Figure 4 presents the players' perception of the difficulty level in completing the game's phases, as well as their level of confidence in handling geographical orientation objects after experiencing the application. It can be seen (Fig. 4a) that only 9.7% of those surveyed found the game too easy or too difficult, which is a good indicator of the game's level of immersion. Additionally, 96.8% of participants reported increased confidence in using spatial orientation tools after interacting with the game.. This result reinforces the quantitative findings, suggesting that the positive evaluations are associated with positive perceptions regarding the educational value of the game.

5.5. Discussion

The results provide converging evidence of high engagement and positive perceptions regarding the educational potential of the proposed game. The high median values,

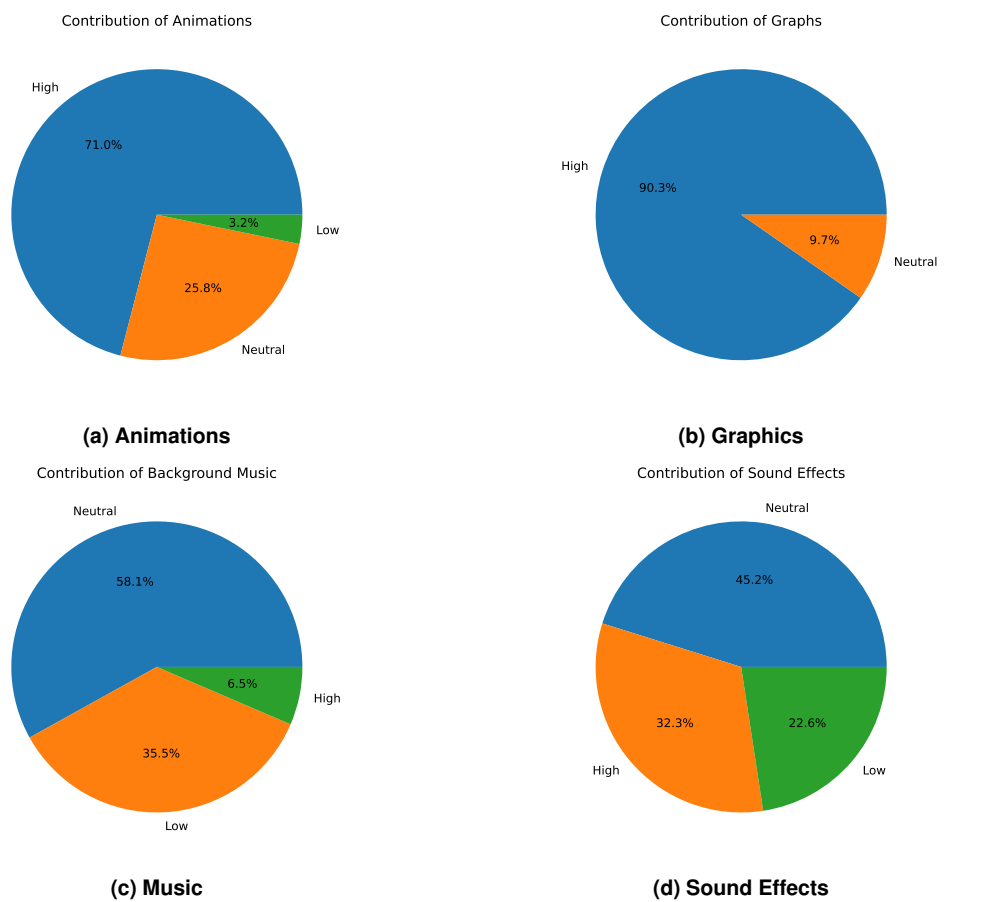


Figure 3. Contribution of game elements.

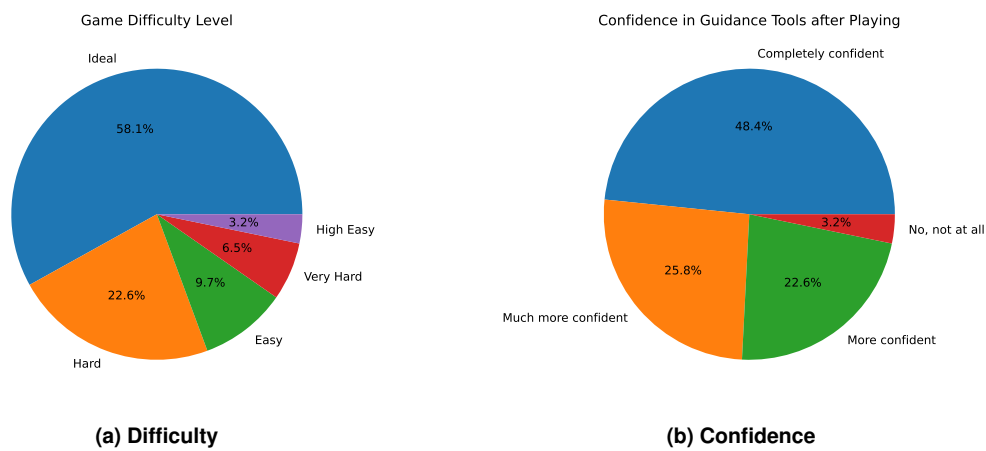


Figure 4. Difficulty and confidence.

combined with statistically significant Wilcoxon test results and large effect sizes, indicate that participants' positive evaluations are systematic rather than incidental.

From a theoretical perspective, these findings support the notion that interactive and goal-oriented environments are expected to support learning by transforming abstract concepts into actionable tasks. The strong performance in engagement-related items suggests that the game successfully incorporates key motivational elements such as feedback, challenge, and progression.

The superior evaluation of visual elements reinforces the central role of visual representations in spatial cognition. This result is consistent with the premise that spatial understanding depends heavily on external representations, such as maps and visual cues, which are effectively integrated into the game design.

The reported increase in confidence further indicates that the game may support activities aimed at developing spatial thinking skills by allowing players to repeatedly apply navigation concepts in progressively complex scenarios. This aligns with the idea that participants perceived the interaction as helpful for understanding spatial concepts rather than passive exposure.

However, some limitations must be acknowledged. The sample size is relatively small ($N = 31$), and the evaluation relies on self-reported perceptions rather than objective performance measures. Additionally, the strong concentration of responses in the upper range of the scale may introduce ceiling effects, limiting the ability to discriminate between levels of user experience.

Despite these limitations, the consistency between descriptive statistics and inferential results suggests that the observed effects are robust. Future work should include larger and more diverse samples, as well as objective assessments of spatial skill acquisition, to further validate the effectiveness of the approach.

6. Conclusions and Future Work

This study presented the design, development, and evaluation of Labyrinth of Traps, an educational digital game aimed at supporting the learning of spatial orientation concepts through progressive challenges in 2D and 3D environments.

The results consistently indicate that participants positively perceived that the proposed approach has potential in promoting engagement and positive perceptions regarding its educational usefulness. Descriptive analyses indicated that participants' responses were concentrated in the upper range of the Likert scale, with median values equal to or above 4 across all evaluated items.

Inferential analysis, conducted using the Wilcoxon signed-rank test, demonstrated that all evaluated dimensions were significantly above the neutral baseline. Furthermore, the observed effect sizes were consistently large, indicating that the differences are not only statistically significant but also practically meaningful. These findings suggest a strong and systematic tendency toward positive evaluations of the game.

In addition, the high percentage of participants reporting increased confidence in the use of spatial orientation tools reinforces the educational potential of the proposed approach. The integration of multiple navigation mechanisms (e.g., compass, maps, radar,

and celestial references), combined with the transition between allocentric and egocentric perspectives, appears to provide an environment suitable for practicing spatial orientation concept.

From a pedagogical standpoint, the results indicate that structured and interactive environments may help reduce the perceived abstraction by transforming them into actionable tasks. The strong performance of visual elements further highlights the importance of graphical representations in spatial learning.

Despite these promising results, some limitations must be acknowledged. The study relied on a relatively small sample ($N = 31$), which may limit generalizability. Additionally, the evaluation was based on self-reported perceptions rather than objective performance measures, and the concentration of responses in the upper range of the scale suggests the presence of potential ceiling effects. Finally, because the evaluation relied on self-reported perceptions collected after gameplay, no direct conclusions can be drawn regarding actual learning gains or improvements in spatial thinking.

Future work should address these limitations by conducting studies with larger and more diverse samples, as well as incorporating objective metrics of learning, such as task performance, accuracy, and completion time. Experimental designs with control groups would also allow for stronger causal inferences regarding the effectiveness of the game.

Furthermore, future developments may explore enhancements in multimodal feedback, particularly the integration of spatial audio cues to complement visual information. Adaptive difficulty mechanisms and personalized learning paths also represent promising directions for improving user experience and pedagogical effectiveness.

Ultimately, extending the game to different educational contexts and age groups may contribute to a broader validation of its applicability as a tool for teaching spatial orientation and cartographic literacy.

Relevant Information

During the drafting of this manuscript, the authors employed the ChatGPT language model to refine stylistic clarity and enhance readability. Following this automated assistance, the authors meticulously reviewed and revised the generated text to ensure accuracy. The authors maintain full accountability for the final integrity and content of this publication.

The project of this work are available in <https://github.com/arthurbracarense/LabirintoDasArmadilhas>.

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