An Exploratory Study of an Evidence-Based Augmented Reality Board Game for Paleontology Learning

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***Abstract. Introduction**: Educational games and augmented reality (AR) have been explored to support science learning, but often prioritize visualization and interaction over structured reasoning and knowledge construction. **Objective**: This paper presents the design and evaluation of PaleoExtinção, a hybrid board game that combines physical gameplay and AR to support the learning of paleontological concepts through evidence-based interaction. **Methodology**: A pilot study with undergraduate students in a Biological Sciences teacher education program used pre- and post-tests to assess learning outcomes and a Likert-scale questionnaire to capture participants' perceptions. Data were analyzed using a paired t-test and descriptive statistics. **Results**: Participants showed improved performance after the intervention ($t(6) = 7.13$, $p < 0.001$; Cohen's $d = 2.69$), and reported positive perceptions of engagement and motivation. Although the small sample and absence of a control group limit the generalizability of the findings, the pilot study provides preliminary evidence of the feasibility of combining physical gameplay, augmented reality, and evidence-based mechanics to support engagement and understanding of paleontological concepts. The evaluation with pre-service teachers also offers initial insights into the pedagogical applicability of the approach.*
***Keywords** Educational Games, Augmented Reality, Hybrid Board Games, Paleontology Education, Teacher Education*

1. Introduction

Educational games have been widely explored as tools to support teaching and learning processes, particularly in science education, where complex and abstract concepts can benefit from interactive and visual approaches [Schwanke and Silva 2010]. Game-based learning environments can promote engagement and facilitate knowledge construction by combining elements such as challenge, feedback, and active participation [Prensky 2003, Savi and Ulbricht 2008, Souza-Concilio and Pacheco 2013]. In parallel, Augmented Reality (AR) has emerged as a promising educational technology, enabling the visualization of structures and phenomena that are difficult to observe directly and contributing to more concrete and immersive learning experiences [Akçayır and Akçayır 2017, Belo 2018, Garzón et al. 2019].

Despite these advances, existing approaches often focus either on fully digital environments or on traditional physical materials, with limited integration between both [Muschio et al. 2015, Ali et al. 2022]. In particular, while AR has been successfully applied to enhance visualization, many educational applications still rely on interaction models centered on content presentation or simple question-and-answer formats, offering limited support for structured activities that explicitly require the progressive integration and interpretation of information [Garzón et al. 2019]. The combination of physical board games with AR resources provides an opportunity to integrate tangible interaction with digital augmentation. This approach aligns with concepts such as Educational Games Virtualization, which aims to preserve pedagogical aspects of physical games while incorporating contemporary digital elements [Santos and Silva Junior 2016]. However, this approach remains underexplored in terms of how gameplay can support the interpretation and integration of information over time. This limitation is especially relevant in domains such as paleontology, where understanding depends on connecting multiple pieces of evidence and contextualizing abstract concepts [Damala et al. 2008, Xiaohui et al. 2012, González-Delgado et al. 2020].

There is also a need to investigate educational technologies within teacher education, since pre-service teachers may later influence the adoption of innovative pedagogical practices [Tondeur et al. 2012]. Although AR has demonstrated educational benefits, challenges such as technical complexity and teacher resistance remain [Bacca et al. 2014, Burns 2023]. In this context, this paper presents the design and evaluation of PaleoExtinção, a hybrid educational board game that integrates physical gameplay and augmented reality to support the progressive collection, interpretation, and application of paleontological evidence. The game was also conceived as a reusable structure adaptable to different educational contents and contexts.

To evaluate its educational potential, an initial pilot study was conducted as a first step in a broader evaluation process, involving undergraduate students enrolled in a pre-service Biology teacher education program. A subsequent stage involving middle school students (6th and 7th grades) is planned but was not included in this phase due to the need for additional preparation and ethical approval. The study investigated learning outcomes through pre- and post-tests, as well as participants' perceptions of the experience. As a pilot study [van Teijlingen and Hundley 2001], the findings provide preliminary evidence of the potential of combining board games and augmented reality to support paleontology learning and teacher education. The main contributions of this work are: (i) the design of a hybrid educational game integrating physical interaction and augmented reality with an emphasis on progressive knowledge construction; and (ii) a preliminary empirical evaluation of its impact on learning outcomes in the context of pre-service teacher education.

2. Related Work

Paleontology remains underexplored in primary and secondary education, being more commonly concentrated in research institutions, universities, and museums. This scenario reinforces the need for strategies to promote its integration into the classroom and stimulate students' interest in this area of natural sciences [Boelter and Goldschmidt 2023]. In this context, the Brazilian National Common Curricular Base (BNCC) highlights the importance of developing scientific knowledge through active, contextualized, and technology-supported learning approaches, encouraging student protagonism and the use of digital technologies in education [Brasil. Ministério da Educação 2018]. Such guidelines support the adoption of innovative pedagogical strategies to address complex and abstract topics, such as those found in paleontology [Costa and Scheid 2022, Marcon et al. 2023].

2.1. Educational Games for Science Learning

Educational games have been widely explored as tools to support teaching and learning in science education. Studies indicate that game-based approaches can promote active learning, increase student motivation, and facilitate the understanding of complex or abstract concepts by enabling learners to interact with simulated scenarios [Savi and Ulbricht 2008]. Several studies report positive outcomes when games are used in science education. For example, [Neves et al. 2010] proposed a board game to support the teaching of basic paleontological concepts, reporting increased student interest and engagement. Similarly, [Reuss and Gardulski 2021] developed a game-based activity for historical geology and paleontology, showing improvements in student motivation and learning outcomes. More recent approaches also highlight the potential of interactive and digital environments to support scientific inquiry and conceptual understanding [Huang et al. 2021].

Despite these advances, many existing approaches rely either on traditional board game mechanics or fully digital environments, often explored in isolation. While these approaches demonstrate positive effects on engagement and learning, they typically emphasize content interaction or presentation, with limited support for processes involving the progressive integration and interpretation of information. This indicates a gap not only in the integration of physical and digital elements but also in how gameplay structures can support reasoning and knowledge construction over time.

2.2. Augmented Reality in Education

Augmented Reality (AR) has gained increasing attention in educational research due to its ability to combine virtual elements with the real-world environment [Garzón et al. 2019]. AR systems enable the superimposition of digital information onto physical objects, allowing learners to interact with visualizations that would otherwise be difficult to observe directly [Billinghurst et al. 2015]. This characteristic is particularly relevant in domains involving spatial structures or abstract scientific phenomena, where AR can support a more concrete and contextualized understanding [Carmigniani and Furht 2011].

Despite these advantages, previous studies also report important challenges associated with the use of AR in education. According to [Akçayır and Akçayır 2017], issues such as usability limitations, technical constraints, and the risk of cognitive overload may negatively impact the learning experience, especially when learners are required to process multiple sources of information simultaneously. These findings highlight the importance of carefully designing AR-based learning experiences to balance interactivity and cognitive demand.

Several studies have explored the application of AR in educational contexts, particularly in informal learning environments. For instance, [Damala et al. 2008] used mobile AR to enrich museum visits by linking digital content to physical exhibits, enhancing contextualization and engagement. Similarly, [Muschio et al. 2015] designed an AR-based game to transform museum environments into interactive learning spaces, reporting positive user perceptions. In classroom contexts, [Bressler and Bodzin 2013] demonstrated that AR-based learning environments can promote engagement, collaboration, and characteristics associated with flow.

Although these approaches demonstrate the potential of AR to enhance learning experiences, particularly through visualization, engagement, and interaction, most studies emphasize the presentation of augmented content rather than the design of structured learning processes that explicitly support reasoning and knowledge construction. While some research reports collaborative and inquiry-based uses of AR, fewer studies investigate how these elements are systematically integrated into gameplay or learning activities that require the progressive interpretation and application of information. In particular, the combination of AR with physical elements in a way that supports evidence-based reasoning and collaborative interaction remains comparatively underexplored [Bacca et al. 2014, Akçayır and Akçayır 2017].

2.3. AR Applications for Paleontology Education

Previous studies have explored the use of augmented reality (AR) to support the learning of paleontological concepts by enhancing visualization and interaction. For instance, [Xiaohui et al. 2012] proposed the Paleontology Magic Book, in which AR markers embedded in printed materials allow for the visualization of three-dimensional models. Similarly, [Guo et al. 2017] investigated the use of AR applications to support learning about dinosaurs in science education, reporting improvements in student engagement and understanding. These approaches demonstrate the potential of AR to make abstract or historical content more tangible and accessible to learners.

In addition to classroom-oriented applications, AR has also been used to enrich experiences in informal learning environments. [Bimber and Raskar 2002] presented an approach that combines real fossil specimens with computer-generated visualizations to reconstruct anatomical structures, enabling a more comprehensive understanding of extinct organisms. Likewise, [González-Delgado et al. 2020] developed an AR application to support the exploration of geological heritage sites, allowing learners to interact with contextualized scientific information in situ. Such approaches highlight the potential of AR technologies to enhance engagement and understanding when compared to traditional static interpretive media.

In spite of these advances, most existing approaches focus either on digital AR applications or on static physical materials enhanced with visualization features. Few studies investigate learning environments that combine augmented reality with structured gameplay requiring the progressive collection, interpretation, and application of information. This gap is particularly relevant in paleontology education, where understanding complex phenomena depends on integrating multiple sources of evidence and contextualizing abstract concepts [Davis et al. 2022]. In this context, the present work explores the integration of augmented reality into a physical board game designed not only to enhance visualization but also to support reasoning and knowledge construction through evidence-based gameplay. This approach seeks to extend existing AR applications by incorporating structured interaction mechanisms that go beyond content presentation, aligning with educational practices that emphasize active learning and conceptual understanding.

3. Game Design Overview

The design of *PaleoExtinção* was inspired by the educational board game *Paleodetetive*, proposed by [Neves et al. 2010]. Both games are based on the progressive construction of knowledge through the collection and interpretation of paleontological evidence. *Paleodetetive* is a fully physical board game structured around the collection and interpretation of evidence whereas *PaleoExtinção* reinterprets this educational premise in a hybrid format, combining physical components with augmented reality features and a different gameplay structure.

The proposed solution is a hybrid educational game composed of a physical layer and a digital layer. The physical layer includes the board, cards, and pawns (Figure 1). These elements structure player progression and provide the informational fragments used throughout the match. As players move across the board, they collect cards containing information about different hypotheses related to the Cretaceous mass extinction. These cards must be interpreted and retained during gameplay, serving as evidence to support later explanations. In this context, the term evidence-based refers to the gameplay requirement that players use the information collected from cards and AR representations as evidence to justify their final explanation, rather than merely selecting an answer from isolated prompts.

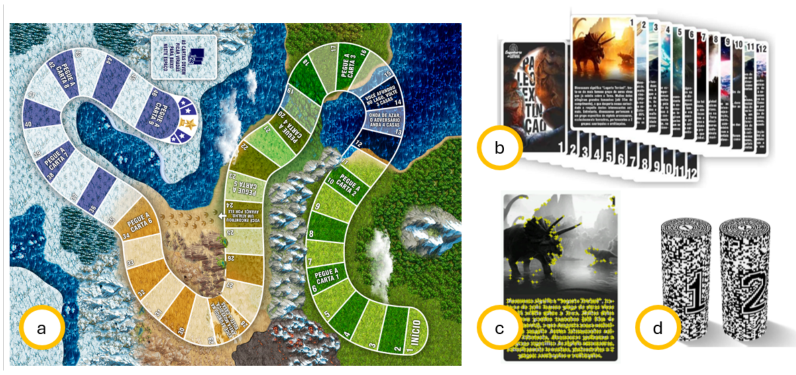

Figure 1. Physical components of PaleoExtinção: (a) game board, (b) cards, (c) AR recognition points on a card, and (d) player pieces.

The digital layer consists of a modular mobile application developed in Unity [Unity Technologies 2025], with Vuforia-based augmented reality [PTC Inc. 2026]. In this layer, cards and cylindrical pawns are used as recognition targets for the visualization of three-dimensional content associated with specific game elements (Figure 2). The development process was also supported by prototyping and lightweight software engineering practices, including interface design, task organization, and version control.

3.1. Gameplay

When landing on specific positions, players read the card content aloud and interact with augmented reality elements that provide complementary visual representations of paleontological concepts. In this interaction, the physical cards do not function only as

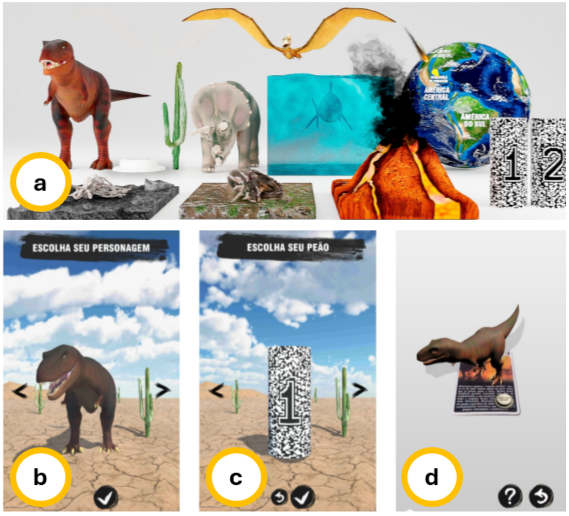

Figure 2. Digital components of PaleoExtinção: (a) 3D elements created for the game, (b) character selection screen, (c) pawn selection screen, and (d) in-game visualization of the selected character.

textual prompts. The first nine cards are also used as image-based recognition targets for the mobile application. When a player collects one of these cards, the card can be scanned with the device camera to display a corresponding 3D model related to the paleontological hypothesis described in the text. Thus, the AR layer complements the physical component by connecting written evidence to an interactive visual representation, which can later be used by players when constructing their final explanation about the extinction event.

The core gameplay is based on a progressive cycle of information acquisition, interpretation, and application. Rather than relying on isolated questions, players are required to accumulate and connect information obtained during the game. The match concludes when a player reaches the final position, at which point they must formulate an explanation for the extinction event using the evidence gathered throughout gameplay. This explanation is discussed with the opposing player and may be supported by previously collected cards. The process is mediated by the instructor, who supervises the activity and ensures that the reasoning presented is coherent and aligned with the scientific concepts addressed.

This structure emphasizes reasoning and knowledge construction by requiring players to integrate multiple pieces of information and apply them in a meaningful context. The challenge is not limited to recalling isolated facts, but involves interpreting relationships between concepts and constructing explanations based on accumulated evidence [Barkley et al. 2014]. The AR component supports this process by visualizing structures and phenomena that are difficult to observe through traditional instructional materials. For example, while printed textbook images usually present extinct organisms or geological events as fixed two-dimensional representations, the AR layer displays a three-dimensional element directly linked to the card content, allowing learners to inspect it within the context of the evidence being discussed. This comparison is conceptual rather than experimental, since the study did not isolate the effect of AR in relation to printed materials. Finally, the game was designed as a reusable structure, allowing modifications of content and visual elements to support different subjects and learning contexts.

4. Method

4.1. Research Design

This study adopts a pilot study [van Teijlingen and Hundley 2001] design with a formative evaluation perspective, commonly used in early-stage educational interventions to support iterative refinement prior to large-scale implementation [Tessmer 1993]. The study is grounded in a previous systematic mapping of the literature on educational games and augmented reality in science education (t.ly/IxTrb). A within-subject design was employed, with data collected before and after the gameplay session. The evaluation focused on two dimensions: (i) learning outcomes, assessed through pre- and post-tests, and (ii) participants' perceptions, particularly regarding motivation and engagement, assessed through a Likert-scale questionnaire. Given the exploratory nature of this study and the small sample size, the results are intended to provide preliminary evidence rather than confirmatory findings [van Teijlingen and Hundley 2001].

4.2. Participants

Participants were recruited from undergraduate students enrolled in a Biological Sciences teacher education program. A total of 23 students were invited to participate; 7 volunteered and completed all stages of the study. As pre-service teachers, participants represent a relevant population for evaluating the pedagogical potential of educational technologies. All participants provided informed consent prior to the study. Due to the odd number of participants, one student participated in two gameplay sessions, playing with different peers to maintain the activity's pairing structure. Only one set of responses per participant was considered in the analysis. This configuration may have introduced a minor familiarity effect; however, given the exploratory nature of the study and the focus on preliminary evidence, its impact is considered limited [Shadish et al. 2002].

4.3. Instruments

Learning outcomes were assessed using a 10-item multiple-choice test covering the paleontological concepts addressed during gameplay. The instrument was designed to reflect the game's core and was reviewed for clarity and alignment with the intended learning objectives. Content validity was supported through consultation with a domain expert in paleontology, ensuring the accuracy and relevance of the assessed concepts. The same test was administered before and after the intervention to allow direct comparison of performance. While this approach ensures comparability, it may introduce testing effects, a limitation acknowledged in the study.

Participants' perceptions were assessed using a Likert-scale questionnaire composed of statements related to motivation, engagement, and perceived usefulness of the game as a learning tool. Responses were recorded on a five-point scale ranging from "strongly disagree" to "strongly agree." An additional open-ended question was included to collect qualitative feedback. Due to the exploratory nature of the study and the limited sample size, no inferential validation of the instruments (e.g., factor analysis) was performed. The instruments used in this study can be accessed at the following link (t.ly/IxTrb).

4.4. Procedure

The study was conducted in a controlled classroom environment and followed five sequential stages within a single session. (i) First, participants signed an informed consent form. (ii) Next, they completed the pre-test to assess prior knowledge. (iii) In the third stage, participants interacted with the *PaleoExtinção* game. Gameplay was organized in pairs, with two players per board, and lasted approximately 20 to 30 minutes. During this stage, players progressed along the board, collected informational cards related to hypotheses about the Cretaceous mass extinction, and used the mobile application to access the corresponding AR content when available. Card content was read aloud and interpreted collaboratively, and participants were instructed to consider both the textual and augmented information when discussing the final explanation. (iv) After gameplay, participants completed the post-test. (v) Finally, they answered the perception questionnaire.

4.5. Data Analysis

Learning outcomes were analyzed by comparing pre- and post-test scores using a paired t-test. Before applying the paired test, the distribution of the differences between paired observations was examined visually. To complement the statistical analysis, effect size was calculated using Cohen's d, providing an estimate of the magnitude of the observed differences [Morettin and Bussab 2010]. Descriptive statistics (mean, median, and standard deviation) were used to summarize participants' performance in both tests. Responses to the perception questionnaire were also analyzed using descriptive statistics due to the limited sample size. As this is a pilot study without a control group, the results are not intended to establish causal relationships but rather to provide initial evidence regarding the potential of the proposed approach [van Teijlingen and Hundley 2001].

5. Results

5.1. Motivation Results

The perception questionnaire included four Likert-scale items addressing attractiveness, AR-related motivation, applicability to other subjects, and overall appreciation. All participants ($n = 7$) strongly agreed with all items, resulting in $M = 5.00$ and $SD = 0.00$ for each item. These results indicate a favorable perception of the game, although they should be interpreted descriptively due to the small sample size and exploratory nature of the study. Table 1 summarizes the descriptive results.

Table 1. Descriptive results of the perception questionnaire

Questionnaire item	Mean	SD	Strong agreement
The game was more attractive than a regular class	5.00	0.00	7/7
AR motivated me to learn more	5.00	0.00	7/7
Applying the game to other subjects is interesting	5.00	0.00	7/7
I liked the game	5.00	0.00	7/7

5.2. Learning Gain

The comparison between pre- and post-test scores revealed an increase in participants' performance after the intervention. A paired t-test indicated that this difference was statistically significant ($t(6) = 7.13$, $p < 0.001$), with a large effect size (Cohen's $d = 2.69$). Table 2 presents the individual scores and descriptive statistics for both tests, while Figure 3 illustrates the individual score progression from pre-test to post-test. The mean score increased from 51.4 in the pre-test to 85.7 in the post-test, while the median increased from 50 to 90. The standard deviation remained relatively stable (9.0 and 9.8), indicating that score variability did not change substantially.

Table 2. Student Scores and Descriptive Statistics

Participant	Exam A	Exam B
Student 1	60	100
Student 2	60	90
Student 3	50	80
Student 4	40	80
Student 5	60	70
Student 6	40	90
Student 7	50	90
Mean	51.4	85.7
Median	50	90
Standard Deviation	9.0	9.8

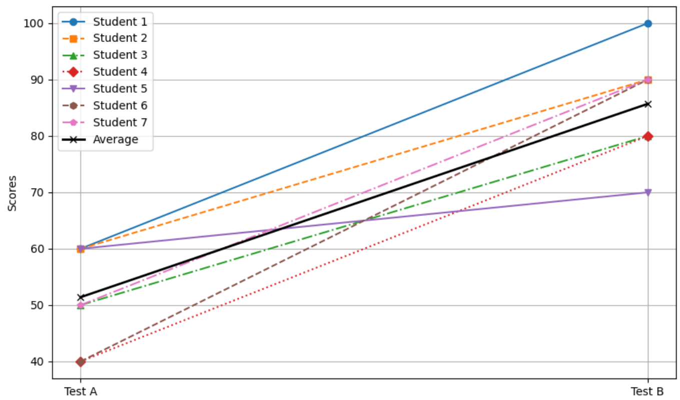

Figure 3. Individual score progression from pre-test (Test A) to post-test (Test B).

6. Discussion

The results provide initial evidence regarding the potential of a hybrid board game in which physical components, augmented reality, and evidence-based gameplay operate as complementary layers to support motivation and learning in paleontology education. Participants reported positive perceptions of the experience, and their post-test scores improved after the intervention. Given that the participants were pre-service teachers, these findings also suggest pedagogical potential for future classroom integration, although they should be interpreted cautiously due to the exploratory nature of the study.

From a design perspective, the game structure may have supported understanding by requiring players to progressively collect, interpret, and apply information throughout gameplay. Rather than relying only on isolated questions, players used accumulated evidence to construct explanations about the extinction event. The interaction between players, combined with instructor mediation, introduced elements of collaborative reasoning, in which participants articulated and refined their understanding through discussion [Mazur 1997, Bochennek et al. 2007]. Future work should conduct controlled studies with larger and more diverse samples, including students from basic education, to better evaluate the effectiveness of the proposed approach. Further investigations should also explore adaptations of the game to different subject areas and educational contexts, as well as its potential impact on teaching practices in real classroom settings.

6.1. Threats to Validity

This study presents limitations that should be considered when interpreting the results. First, the small sample size limits the generalizability of the findings and reduces the robustness of the statistical analysis. In addition, voluntary participation may have introduced self-selection bias. Second, the study adopted a within-subject design without a control group, which prevents isolating the intervention's effects from other potential influences. The use of the same instrument in the pre- and post-test may also have introduced a testing effect, since participants could remember items from the first application. Instructor mediation may have influenced participants' reasoning during gameplay, making it difficult to separate the effects of the game artifact from the support provided during the activity. Finally, due to the odd number of participants, one student participated in two gameplay sessions, which may have introduced a minor familiarity effect and influenced interaction dynamics. Given these limitations, the results should be interpreted as preliminary evidence rather than definitive conclusions about the effectiveness of the proposed approach.

7. Conclusion

This paper presented the design and preliminary evaluation of *PaleoExtinção*, a hybrid educational game that combines a physical board game with augmented reality to support the teaching of paleontological concepts. The main contribution of this work is a reusable hybrid game structure that integrates physical interaction, augmented reality, and evidence-based gameplay, rather than a general classroom experience report. The findings of the pilot study provide initial evidence that this integration can support engagement and understanding of paleontological concepts. In particular, the requirement for players to collect, interpret, and apply information throughout the game highlights the potential of the approach to promote active participation and reasoning. The evaluation with pre-service teachers also provides initial insights into its pedagogical applicability. As a pilot study, the results should be interpreted cautiously. Future work will focus on conducting controlled studies with larger and more diverse samples, including students from basic education, to better assess the educational impact of the approach. Further investigations will also explore adaptations of the game to other subject areas and its application in real classroom settings.

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