IsoPuzzle: Development and Evaluation of an Ethno-Educational Serious Game

Thiago Emanuell V. Moura ⓘ ✉ [**Universidade Federal de Goiás** | *thiagoemanuell@discente.ufg.br*]
Jaqueline Araújo Civardi ⓘ [**Universidade Federal de Goiás** | *jaqueline@ufg.br*]
Mary Anne Vieira Silva ⓘ [**Universidade Estadual de Goiás** | *mary.silva@ueg.br*]
Luciana de Oliveira Berretta ⓘ [**Universidade Federal de Goiás** | *luciana.berretta@ufg.br*]
Sergio Teixeira de Carvalho ⓘ [**Universidade Federal de Goiás** | *sergiocarvalho@ufg.br*]

✉ *Instituto de Informática, Universidade Federal de Goiás, Alameda Palmeiras, Quadra D, Câmpus Samambaia, Goiânia - GO, 74690-900, Brazil.*

Abstract: This study presents the development and evaluation of IsoPuzzle, a digital ethno-educational game that merges progressive isometric geometry challenges with Adinkra symbolism to integrate mathematical concepts and African cultural elements. Based on Game-Based Learning (GBL) and the PEED methodology, IsoPuzzle promotes collaboration and active stakeholder participation. Its evaluation, conducted via a structured questionnaire derived from frameworks such as SUS, MEEGA+, PAJDE, and IAQJEd, focused on three indicators: pedagogical engagement, accessibility and usability, and the impact of cultural immersion on player experience (PX). Results indicate that IsoPuzzle effectively combines mathematical abstraction with engaging visuals, enhancing cultural connections through the use of Adinkra symbolism. The analysis also identified areas for refinement, particularly related to instruction clarity and interface accessibility, indicating the need to improve navigational intuitiveness. The data proved reliable, with the educational dimension averaging 4.16 (SD = 0.91), the cultural dimension 3.78 (SD = 1.02), and the user experience 3.61 (SD = 1.08). Variations in device quality further influenced user experience, underscoring the need for multi-platform optimization. Overall, these findings provide valuable insights for refining digital teaching tools that strike a balance between mathematical rigor, cultural diversity, and interface efficiency.

Keywords: Serious Games, Game Evaluation, Education and Culture, User Experience, Ethno-education, Cultural Narratives, Inclusion and Diversity

1 Introduction

Geometry plays a fundamental role in developing logical and spatial reasoning, constituting one of the cornerstones of mathematics education. However, its assimilation poses a challenge for many students due to the high level of abstraction inherent in its concepts. The difficulty in visualizing and manipulating geometric objects in a traditional learning environment can hinder comprehension, resulting in low academic performance and diminished interest in the subject. This scenario highlights the importance of didactic methodologies that enhance accessibility, dynamism, and contextualization in the learning process [Prensky and Thiagarajan, 2007; Paiva and Silveira, 2021].

At the same time, the high dropout rate during the transition from elementary to high school in Brazil underscores the urgency of pedagogical approaches that foster students' active engagement in the educational process [Barreto and Sampaio, 2024]. Integrating digital games into teaching has been established as an effective alternative for enhancing learning, offering interactive experiences that promote knowledge construction in a playful and exploratory manner.

Studies indicate that educational games can stimulate the development of critical thinking, problem-solving skills, and creativity while enhancing student engagement [Titus and Ng'ambi, 2023; Randle, 2024]. Serious games, which integrate entertainment elements with pedagogical objectives, have been widely applied across various domains, including education, healthcare, and professional training, demonstrating their potential to foster greater engagement and deeper conceptual understanding [Huizinga, 2008; Murray, 1997].

In mathematics education, digital games have been shown to engender an environment conducive to experimentation and the practical application of geometric concepts. The ability to manipulate figures, test hypotheses, and solve structured challenges fosters active and meaningful learning, enabling students to develop cognitive skills and enhance their analytical abilities [De Guzman Quinto, 2021]. Consequently, the use of educational games emerges as a valuable strategy to transform geometry teaching, rendering it more engaging and contextually relevant.

Beyond the pedagogical dimension, the cultural representation in the development of teaching materials and technological educational resources has become an increasingly relevant topic [Ginane and Montenegro, 2025]. In Brazil, Law No. 10.639/03[1] mandated the inclusion of Afro-Brazilian History and Culture in the school curriculum to enhance the recognition of these populations' contributions to the formation of national identity. Nevertheless, the effective implementation of this directive still faces challenges, as cultural

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[1]Brazil (2003). Law No. 10.639 of January 9, 2003. Official Gazette of the Federative Republic of Brazil. https://www.planalto.gov.br/ccivil_03/Leis/2003/L10.639.htm Accessed: 29 June 2025

content is often fragmented and lacks methodologies that facilitate its organic and engaging integration into formal education [Souto Maior, 2024].

In this context, the literature emphasizes the importance of developing educational materials that incorporate cultural diversity. For instance, Ginane and Montenegro [2025] presents a study that, using qualitative and quantitative methods — such as questionnaires, document analysis, and pedagogical workshops — demonstrated that training teachers and administrators for the effective inclusion of Afro-Brazilian history and culture helps raise awareness about structural racism and enhances cultural representation in school practices. This occurs despite challenges such as initial resistance from educators, the scarcity of teaching materials, and difficulties adapting the curriculum.

This article presents the *IsoPuzzle*[2], a game designed as an educational tool that integrates the teaching of geometric transformations with the appreciation of African culture through Adinkra symbology. The latter is a graphic representation system used by West African peoples [Dutra and Maciel, 2024; Quarcoo, 1994; Willis, 1998]. *IsoPuzzle* presents mathematical challenges that foster an understanding of fundamental geometric concepts and immerses players in cultural elements that have historically been underrepresented in the educational system. The game establishes connections between mathematics and culture, fostering an appreciation of diversity and encouraging reflection on the importance of representation in education. This study contributes to pedagogical practices by demonstrating how digital games can support interdisciplinary and culturally integrated learning.

The text of this article is an extended and revised version of a paper previously published in the Brazilian Symposium on Games and Digital Entertainment (SBGames) [Moura *et al.*, 2024]. The article's primary improvements include, firstly, the presentation of the fundamental characteristics of the game and its potential as an ethno-educational teaching tool, and secondly, an evaluation of *IsoPuzzle* across three dimensions: pedagogical, cultural, and user experience (UX). The study analyzed players' interactions with the game, considering the intuitiveness of the controls, the navigability of the interface, and the suitability of visual and functional elements. The findings offer insights for optimizing the interface, enhancing accessibility, and improving the immersive experience, thereby making the game more adaptable to diverse user profiles and educational contexts.

In addition to this introductory section, the article is organized into five sections. The second section presents the theoretical foundations supporting the development of *IsoPuzzle*, emphasizing the interrelationship between games and culture, specifically African culture and mathematics, as well as the evaluation models for serious games. The third section provides an overview of the game, detailing its characteristics and functionalities. The subsequent section details the methodological approach, including the development and evaluation methods, which employ a combination of techniques and utilize a structured form to measure interest indicators. The fifth section presents and discusses the results

obtained through quantitative and qualitative analyses, emphasizing the impacts on the user experience. Finally, the sixth section summarizes the primary findings and suggests future research directions.

2 Background

2.1 Games and Culture

Despite enacting Law 10.639/2003 in Brazil, recent research suggests that its implementation in educational settings remains encumbered by substantial challenges [de Lima Silva, 2024]. School education continues to be guided by Eurocentric perspectives, limiting the study of African culture to narratives of poverty and slavery. This historical bias erodes the manifold African contributions and roots that have shaped Brazilian culture. Conversely, according to Styhre *et al.* [2018], the intellectual legitimization of video games as cultural artifacts can potentially promote a more diverse array of themes and perspectives, thereby expanding the discourse on cultural representation and the inclusion of historically marginalized knowledge.

An interesting example is discussed in the study by Titus and Ng'ambi [2023], which examines the utilization of digital games to promote intercultural learning within a South African university setting. In this study, the authors developed a learning model grounded in the principles of social constructivism, wherein games serve as a medium to facilitate dialogue between diverse cultures and stimulate critical thinking. The findings suggest that incorporating interactive strategies and collaborative narratives can significantly enhance intercultural understanding, fostering heightened sensitivity to cultural differences within the academic environment.

The authors of the work Kleftodimos *et al.* [2023] address relevant aspects that explore the creation of location-based augmented reality games as instruments for preserving cultural heritage. This approach enables users to experience immersion in historical and cultural spaces, allowing for direct interaction with environments that hold social and historical significance. The study highlights that such games can spark interest in heritage and encourage informal education, facilitating learning by exploring real-world contexts.

Furthermore, the work of Pereira *et al.* [2023] demonstrates that serious games can function as pedagogical tools for exploring aspects of Brazilian culture. It focuses on the interaction between historical elements and regional gastronomic manifestations; the study emphasizes how integrating cultural content with teaching practices can make the learning process more dynamic and engaging. However, the authors highlight the need to enhance the adaptability of the cultural experience to align content with users' existing knowledge and skills, thereby promoting more effective interaction between pedagogical and cultural elements.

These studies highlight the significance of digital games in disseminating knowledge and fostering cultural diversity. While not all the games analyzed focus exclusively on African culture, the research demonstrates that integrating narratives and cultural elements in games can enrich the

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[2]The game *IsoPuzzle* was registered with the National Institute of Industrial Property (INPI) under number BR512023002477-5, with the concession date of August 29, 2023.

learning process and foster intercultural understanding, contributing to the appreciation and preservation of different cultural heritages.

2.2 African Culture and Mathematics

The Ashanti culture, originating from the Akan peoples of Ghana and the Ivory Coast, is captivating for its expressiveness and community values Nascimento and Gá [2009]. In this context, the Adinkra symbols, sets of ideograms rich in historical significance, initially emerged in rituals and adorned royal fabrics, later spreading into various forms of art and decoration.

Each Adinkra symbol has a distinct meaning and is often linked to proverbs or traditional stories that embody ancestral wisdom (Figure 1).

Símbolo	Nome	Significado	Descrição	Símbolo	Nome	Significado	Descrição
◎	Adinkrahene	Chefe dos símbolos adinkra	Grandeza, carisma e liderança		Nea Ope Se Obedi Hene	Aquele que quer ser rei	Serviço, liderança
	Akrofena	Espada de guerra	Coragem, valor		Nkyimu	Divisões do tecido adinkra antes da impressão	Prcisão, habilidade
	Akroben	Corneta de guerra	Vigilância, atenção		Nkonsonkonson	Elos de correntes	União, relações humanas

Figure 1. Some *Adinkra* symbols. Nascimento and Gá [2009].

Below are some examples.

- **Gye Nyame**: One of the most well-known Adinkra symbols, representing the omnipotence and supremacy of God. It is commonly translated as "except God" or "no one except God" [Willis, 1998].
- **Sankofa**: Represented by a bird looking backward with an egg in its mouth or by a stylized heart. This symbol means "return and fetch," as a reminder of the importance of learning from the past [Quarcoo, 1994].
- **Dwennimmen**: Represented by two ram's horns. This symbol represents "humility and strength," teaching that it is possible to be both strong and humble simultaneously [Rattray *et al.*, 1927].
- **Fawohodie**: Symbolizes independence and freedom, reflecting the Akan people's struggle for emancipation and self-determination [Willis, 1998].

Adinkra symbols have evolved beyond their traditional origins, finding widespread application in various forms of art and design. These symbols have been incorporated in clothing, accessories, jewelry, architecture, and logos within the African continent and the African diaspora. The contemporary utilization of these symbols serves as aesthetically pleasing decoration and a medium for preserving and disseminating ancestral wisdom and values [Quarcoo, 1994].

The symbols are frequently found on the grilles of gates and windows in houses, primarily in Ghana and the Ivory Coast. These grilles function both as security elements and as a means of cultural and aesthetic expression [Silva, 2023]. The intricate designs of Adinkra symbols add an artistic and meaningful touch to structures, transforming utilitarian elements into manifestations of cultural identity.

For instance, the presence of the symbol *Fawohodie* on a gate (symbolizing independence and freedom) may convey a message of pride and self-determination of the family residing in that house. Similarly, the symbol *Gye Nyame*, rep-

resenting the supremacy of God, on windows may indicate residents' religious beliefs.

Adinkra symbols are often incorporated into mosaics or pavements on sidewalks and courtyards. These symbols are used not only for decoration but also to tell stories or convey meaningful messages. A courtyard adorned with symbols such as *Sankofa* can elicit a reflective response from visitors regarding the significance of learning from the past. Concurrently, the presence of Nsoromma (star) in trucks or passages can be interpreted as a symbol of hope and guidance, as previously noted by [Silva, 2023].

Integrating Adinkra symbols into architectural and urban design preserves and celebrates cultural heritage, adapting these symbols to modern contexts. This practice fosters a dynamic interaction between tradition and innovation, allowing individuals to establish new and relevant connections with their cultural origins [Quarcoo, 1994; Silva, 2023].

In the context of Brazilian reality, contemporary architects and designers are increasingly incorporating Adinkra symbols into their projects to create spaces that are both aesthetically pleasing and culturally significant [Silva, 2023]. In urban areas, symbols can be found on murals, public buildings, squares, and even in urban furniture, such as benches and light posts, or in residential areas, on grilles and gates. However, these symbols often go unnoticed by many people, as, despite being deeply embedded in Brazilian culture, this theme is rarely disseminated and presented, particularly in schools.

This extensive attention helps maintain the relevance of Adinkra symbols in modern life while promoting ongoing appreciation for African arts and history. In addition to their aesthetic use, Adinkra symbols are significant educational tools. In mathematics, Adinkra symbols exhibit relevant algebraic properties, as evidenced by Gates [2010], which explores these properties using group theory and representation theory. Furthermore, Adinkra symbols offer a unique opportunity for integration into mathematics education, particularly within ethno-mathematics. As Babbitt *et al.* [2015] notes, the geometric patterns inherent in Adinkra symbols can be employed to elucidate mathematical concepts such as symmetry, geometric transformations, and algorithms.

Adinkra symbols exhibit a wide diversity of geometric shapes that can be explored to teach various mathematical concepts [Babbitt *et al.*, 2015]. By analyzing symmetric patterns and isometric transformations, students can better visualize and understand mathematical principles [Babbitt *et al.*, 2015]. For instance, isometric movements such as translations, rotations, and reflections can be facilitated by incorporating Adinkra designs, rendering the learning process more tangible and connected to the local cultural context.

Incorporating Adinkra symbols in mathematics education facilitates the understanding of geometric concepts and promotes teaching that is aligned with cultural perspectives. Using these symbols, educators can connect mathematics to students' sociocultural references, which may influence motivation and interest in the subject. In this context, Babbitt *et al.* [2015] highlights that this ethno-mathematical approach helps build a bridge between abstract mathematics principles and students' cultural experiences, making learning more comprehensive and immersive.

These symbols also play a significant role in string theory, where their mirroring symmetry is fundamental in explaining subatomic particles observed in nature [Abdalla, 1990]. This symmetry is intricately linked to isometric transformations, which maintain the distances and orientations of objects, encompassing reflections, rotations, and translations [Ribeiro, 2016].

Consequently, the Ashanti culture and its Adinkra symbols represent multifaceted themes encompassing history, religion, art, and mathematics. Understanding these symbols within their cultural and mathematical contexts promotes a deeper immersion in the culture and traditions of the Ashanti and Akan peoples, while also highlighting the application of mathematical concepts in unconventional contexts.

2.3 Evaluation Models of Serious Games

The Evaluation of serious games has undergone significant development, anchored in approaches that integrate pedagogical, technological, and user experience (UX) aspects [Fellows *et al*., 2022; Gee, 2003; Oliveira and Rocha, 2021; Hassenzahl *et al*., 2008]. However, a substantial challenge persists: the lack of integrative approaches that systematically and empirically connect educational, cultural, and usability dimensions. This lacuna is especially relevant in domains necessitating nuanced adaptations, such as games designed for special education or professional training, where integrating identity and pedagogical elements is paramount [Fellows *et al*., 2022].

Models such as PAJDE (Program for the Evaluation of Educational Digital Games) [de Souza Santos, 2021] propose rigorous guidelines for curricular alignment, ensuring adherence to formal standards. However, their application of these models has revealed limitations, particularly in evaluating the integration of cultural narratives. This aspect is crucial in initiatives such as *Fables Maker*[3], which is designed for children with Autism Spectrum Disorder (ASD). In this context, personalization and familiar voices amplify user identification and engagement [Scienza and Freitas da Silva, 2024]. Studies linking traditional knowledge to contemporary educational practices emphasize the need for a more comprehensive inclusion of cultural dimensions [Silveira, 2016; Hounsell and Silva, 2021; Oliveira *et al*., 2016].

Another investigative approach, exemplified by IAQJEd [Coutinho, 2017], focuses on UX analysis, prioritizing navigation and interface design. However, this approach neglects the pedagogical effects of the learning process. On the other hand, experiments with *Trate Bem!*[4] — a game aimed at teaching nursing — show that educational effectiveness depends not only on usability but also on the integration of contextual mechanics (such as procedure simulations and ranking systems) and iterative evaluation cycles with the target audience [Scienza and Freitas da Silva, 2024; Rizvic *et al*., 2019]. This finding is further substantiated by a study conducted by [Pereira *et al*., 2023], which designed and evaluated a serious game for teaching Brazilian culture, incorporating cultural elements such as cuisine, historical monuments, and regional stories. The results indicated that, de-

spite favorable usability, the game's effectiveness depends on adjustments to the learning experience and the adaptation of cultural content.

The existing literature also reveals methodological fragmentation, which, according to [Fellows *et al*., 2022], necessitates holistic models. In this context, MEEGA+ [Petri *et al*., 2020] emerges as an advancement, combining player experience and usability variables through a statistically consistent instrument. However, despite its quantitative rigor, MEEGA+ does not address the essential cultural nuances for user immersion, a gap partially filled by the Tétrade Elementar model [Schell, 2014]. The latter integrates the components of narrative, mechanics, technology, and aesthetics, highlighting, for example, how adaptable stories and customizable interfaces can enhance engagement for children with Autism Spectrum Disorder (ASD) [Scienza and Freitas da Silva, 2024]. When applied to the serious game of [Pereira *et al*., 2023], the Tétrade Elementar framework demonstrated potential in articulating visual and mechanical elements. However, the pedagogical modeling still requires further refinement to maximize knowledge retention.

The Evaluation of game quality is further enabled by utilizing specialized tools, such as AttrakDiff [Hassenzahl *et al*., 2008], which facilitates the Evaluation of both pragmatic and hedonic attributes. In the context of studies involving *Trate Bem!*, satisfactory interface connectivity was observed, though weaknesses in visual identity were identified. Similarly, in *Fables Maker*, a robust hedonic dimension was contrasted with a pragmatic quality below expectations, highlighting challenges in predicting game mechanics [Scienza and Freitas da Silva, 2024]. In the study by [Pereira *et al*., 2023], the game's usability was evaluated by judges using adapted SUS (System Usability Scale) metrics, with promising results but indicating the need for improvements in instruction clarity and game mechanics balance to optimize the player experience.

Additionally, the EGameFlow scale [Fu *et al*., 2009] provides a complementary perspective by incorporating eight essential dimensions for evaluating e-learning games, including concentration, goal clarity, feedback, challenge, autonomy, immersion, social interaction, and knowledge improvement. In contrast to the GameFlow model [Sweetser and Wyeth, 2005], which emphasizes the player's ability, EGameFlow values knowledge progression, aligning more precisely with the educational objectives of serious games. The integration of EGameFlow with instruments such as MEEGA+ and Tétrade Elementar establishes a multidimensional evaluation framework, wherein aesthetic and functional dimensions complement each other, thereby enhancing when correlated with cultural narratives or feedback when integrated with usability metrics [Fu *et al*., 2009; Petri *et al*., 2020; Schell, 2014].

The convergence of methodological approaches, including quantitative and qualitative scales, as well as iterative validation processes, has been identified as a promising strategy for evaluating educational games. This integrative perspective can thus overcome the limitations of traditional models, providing a robust foundation for the development and Evaluation of constantly evolving educational gaming environments [Martinez *et al*., 2022; Hunicke *et al*., 2004].

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[3]http://hdl.handle.net/10400.2/16570. Accessed: 29 June 2025
[4]http://hdl.handle.net/10400.2/16570. Accessed: 29 June 2025

3 The IsoPuzzle Game

IsoPuzzle is a puzzle game designed to serve as an educational and cultural tool, bringing students closer to the invaluable yet often overlooked knowledge of our ancestral culture. Comprised of a series of 40 puzzles, the game's structure is designed to present players with increasing levels of complexity as they progress, as illustrated in Figures 2a, 2b, 2c, and 2d.

Each puzzle requires manipulating pieces positioned on a board replete with obstacles. Translation, rotation, and reflection are necessary to achieve the solutions. Engaging with these challenges fosters a clever and analytical approach, developing cognitive skills and problem-solving abilities.
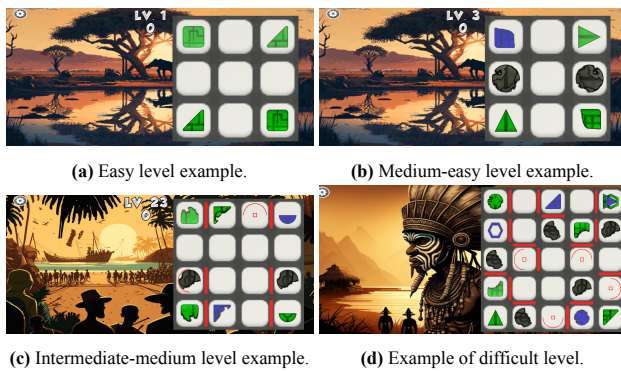

(a) Easy level example. **(b)** Medium-easy level example.

(c) Intermediate-medium level example. **(d)** Example of difficult level.
Figure 2. Increasing difficulty of levels. Source: authors.

The meticulous design of each puzzle entails establishing a minimum number of moves required for its solution. Players who complete the challenges within this limit are awarded the maximum score (Figure 3a), while performances that closely approximate the minimum receive an intermediate rating (Figure 3b), and those that significantly deviate from the minimum receive the lowest rating (Figure 3c). This evaluation structure fosters a pursuit of excellence in each puzzle while promoting persistence and the continuous improvement of the player's skills.

(a) Final 3-star feedback. **(b)** Final 2-star feedback.

(c) Final 1-star feedback.
Figure 3. Performance feedback. Source: authors.

A distinctive attribute of IsoPuzzle is incorporating Adinkra symbolism as a component of its reward structure. Upon completing each puzzle, players are awarded an Adinkra symbol, which augments their artifact collection within the game and enhances their understanding of African culture. Through the artifact menu (Figures 4a, 4b, 4c, 4d),

players can explore each symbol they receive, along with its name and a contextualization of its cultural meaning.
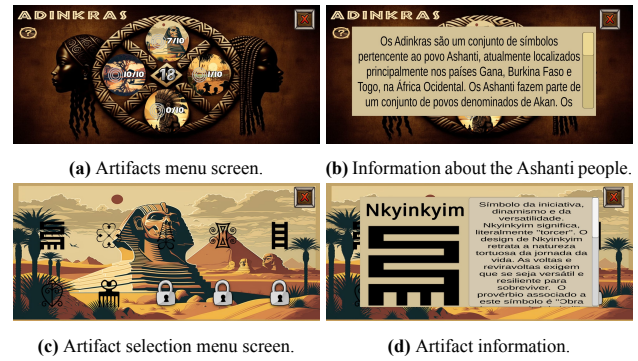

(a) Artifacts menu screen. **(b)** Information about the Ashanti people.

(c) Artifact selection menu screen. **(d)** Artifact information.
Figure 4. Screens related to Adinkra symbolism. Source: authors.

In addition to its educational aspect, IsoPuzzle highlights the theme of African culture, from the visual aesthetics (Figures 5a, 5b, 5c, 5d) to the soundtrack, every element of the game evokes the distinctive traits of this rich cultural heritage. This approach enhances the gaming experience and promotes the appreciation and understanding of cultural diversity among players.
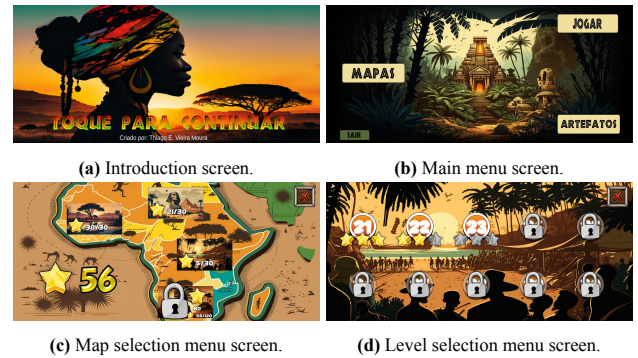

(a) Introduction screen. **(b)** Main menu screen.

(c) Map selection menu screen. **(d)** Level selection menu screen.
Figure 5. Artistic setting. Source: authors.

4 Methodology

4.1 Development Method

The approach adopted in developing the IsoPuzzle game was based on Digital Game-Based Learning (DGBL) [Prensky and Thiagarajan, 2007]. This methodology stands out for its integration of theory and practice in an interactive and participatory manner.

Throughout the development of the IsoPuzzle game, the project involved a literature review on educational game development methodologies, highlighting current trends and the relevance of the adopted approach. This approach also included the PEED methodology (Promotion of Domain Expert Engagement). This mapping identified methods such as the ADDIE model, which structures instructional design in systematic phases [Molenda, 2003]. Design-based research (DBR), which emphasizes iterative cycles of design, implementation, and revision [Anderson and Shattuck, 2012]; and agile approaches, such as Scrum, which promote short iterations and continuous adjustments based on user feedback [Highsmith, 2002], were also identified.

The PEED methodology was selected due to its emphasis on interdisciplinary collaboration and the integration of continuous feedback throughout the development process. According to Américo and Costa Navari [2013], it is essential that a clear pedagogical objective be established from the outset and that domain experts actively participate in the conceptual design process. They emphasize that, given the complexity of development, it is crucial to involve at least three groups of actors: the Technical Development Team (TDT), responsible for visual design, defining mechanics, and coding; the Domain Expert End Users (DEE), accountable for defining and delimiting the pedagogical focus and content; and the Learner End Users (LEU), who represent the target audience.

Given the content selected for the game (isometry), it became necessary to involve an expert in this domain, specifically a PhD professor in mathematics didactics, to oversee the application and adjustments of the content during the implementation phases of the IsoPuzzle game. Additionally, a specialist in African culture joined the team, whose expertise and sensitivity were fundamental in ensuring the accurate and respectful representation of the cultural aspects addressed in the game. This collaborative effort, integrating the expertise of the isometry specialist with that of the African culture specialist, ensured the technical integrity of the mathematical content and the authenticity and cultural relevance of the themes addressed. The synergy between these two areas of knowledge significantly and potentially contributes to creating an enriching and culturally inclusive educational experience for high school students.

The PEED methodology consists of stages, as Figure 6 illustrates. During the conception phase, brainstorming meetings were convened to generate ideas and concepts for the game. Experts in mathematics, African culture, and game design contributed to this project. The specialists guided the specialists in identifying and correcting conceptual issues related to isometric movement and the approach to Adinkra symbols.

Various data collection methods were employed throughout the development process to inform design decisions, including interviews, observations, and document analysis. The tools and technologies used, including 3D modeling software and game engines, were carefully selected to ensure the game's efficiency and quality. Project management was prioritized throughout all project stages, with communication tools, adherence to deadlines, and resource allocation adequately planned. Game design strategies were based on prototyping, usability, and interaction testing to provide users with an engaging and educational experience.

The active involvement of stakeholders proved pivotal in achieving the project's objectives. Teachers, students, and specialists collaborated extensively during the development stages, contributing to the project's success. Moreover, an open and collaborative atmosphere was maintained throughout the process, ensuring that the needs and expectations of all parties involved were addressed promptly and effectively.

4.2 Evaluation Method

This study developed a specific evaluation model for IsoPuzzle, designed to systematically measure the educational, cultural, and user experience (UX) dimensions. The development of the evaluation form involved compiling an initial set of questions from established frameworks (PAJDE, IAQJEd, Meega+, and EGameFlow) [de Souza Santos, 2021; Coutinho, 2017; Petri *et al*., 2020; Fu *et al*., 2009] through a process of selection, filtration, and adaptation. Each question was reviewed to ensure the capture of nuances in user interaction, the clarity of instructional components, and the degree of connection with cultural elements.

The questions were then organized into categories corresponding to the evaluation dimensions, allowing for distinct weighting of each field. Notably, the educational dimension was most emphasized, while the cultural and UX dimensions were weighted according to their relative importance in the game context. Consequently, the evaluation form was designed to balance the multifaceted aspects of the user experience, thereby facilitating a comprehensive assessment of the considered elements.

The adopted mixed approach integrates quantitative metrics, thus enabling the application of statistical techniques for data interpretation and qualitative metrics, which offer insights into users experiences.

4.2.1 Stages of the Evaluation Methodological Process

The evaluation process of the game was structured into six main stages: (i) a review of existing frameworks, (ii) the selection and filtering of questions, (iii) the foundation and relevance of the dimensions, (iv) the practical application to the IsoPuzzle game, (v) data collection, and (vi) analysis and interpretation of results.

4.2.2 Review of Existing Frameworks

The initial stage of the evaluation methodological process for IsoPuzzle involved conducting a comprehensive bibliographic mapping of evaluation frameworks for serious games. This was done to identify established methodological approaches, examine their contributions and limitations, and establish a solid theoretical framework for developing the evaluation form. The structuring of this instrument aimed to ensure that the criteria adopted reflected the specificities of the game, enabling an integrated analysis of the dimensions above in a coherent and methodologically grounded manner.

In response to the limitations of traditional methods, this study proposes an integrative approach based on the models presented in Section 2.3, applied to the context of IsoPuzzle. A thorough analysis of prominent initiatives such as Fables Maker and Trate Bem! [Scienza and Freitas da Silva, 2024] reveals that the integration of iterative testing cycles, cultural adaptations, and the implementation of validated metrics (e.g., AttrakDiff) can harmonize educational objectives, immersion, and accessibility. This approach serves to overcome the prevailing dichotomy between the "serious" and "playful" aspects still present in the field, as previously noted by [Caserman *et al*., 2020].
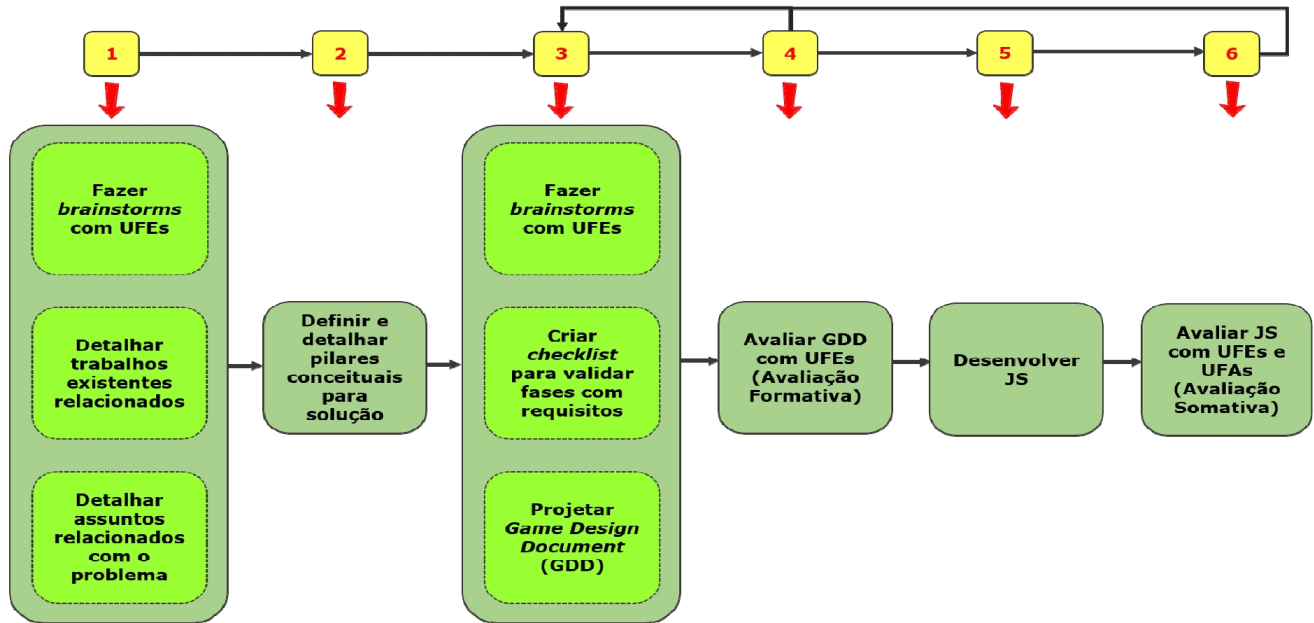
Figure 6. PEED methodology in creating a serious game. Rutes *et al.* [2015]

Furthermore, the bibliographic mapping encompassed contemporary investigations into the inclusion of authentic cultural elements in digital games and their pertinence for strengthening the sociocultural identity of players. Studies such as those by [Silveira, 2016; Quarcoo, 1994; Willis, 1998] demonstrate that the integration of historical symbols, traditional epistemologies, and legitimate cultural expressions not only enhances the depth of the learning experience but also fosters a stronger connection between the player and the content, encouraging the appreciation and preservation of intangible heritage. This approach is particularly relevant in ethno-educational games, where narratives and sociocultural values must be represented with authenticity and sensitivity.

4.2.3 Process of Selection and Filtering of Questions

Each framework reviewed was divided into fundamental evaluative components, such as dimensions, indicators, and specific questions. These elements were categorized according to their relevance to ethno-educational games.

- **Initial Identification:** Initially, 73 questions were gathered from previously established frameworks, namely PAJDE, IAQJEd, Meega+, and EGameFlow [de Souza Santos, 2021; Coutinho, 2017; Petri *et al.*, 2020; Fu *et al.*, 2009], covering educational, cultural, UX, overall impact, and technical and inclusive aspects. The questions were organized into a matrix, categorized by dimension, and accompanied by their respective justifications and bibliographic references.
- **Selection Criteria:** The questions were analyzed based on the following criteria during the screening process.
  - **Contextual Suitability:** Questions that did not align with the educational or cultural focus of ethno-educational games were discarded.
  - **Clarity and Objectivity:** Ambiguous or redundant questions were excluded or reworded to ensure greater precision.

  - **Multidimensional Relevance:** Questions addressing multiple dimensions simultaneously were prioritized, ensuring an integrated analysis.
  - **Flexibility:** Indicators with the potential for adaptation to different types of games and audiences were highlighted for inclusion.
- **Filtering and Adaptation:** 42 questions moved to the refinement stage after the initial screening. The questions were revised during this phase to ensure their applicability to the ethno-educational context. Specific questions were adapted to capture cultural, pedagogical, and technical nuances. For example:
  - "Are the narrative elements of the game coherent?" was refined to "Are the cultural elements represented in the game authentic and respectful?"
  - "Does the game promote engagement?" was revised to "Does the game spark interest in learning more about the represented culture?"
- **Theoretical Validation:** The final selection of 28 questions was subjected to a cross-analysis with the reviewed literature [Fellows *et al.*, 2022; Silveira, 2016; Hounsell and Silva, 2021; Oliveira *et al.*, 2016], ensuring that each question met rigorous content validity and theoretical consistency criteria. The questions were divided into two categories to organize the evaluative items: the first grouping items linked to specific dimensions – educational, cultural, and user experience (UX) – while the second included general questions measuring impact and player satisfaction (PX). Each question was assigned to the corresponding category and weighted according to relevance to reflect the specifics of *IsoPuzzle*.

The result of this process was a refined set of questions that make up the evaluative indicators of the model, as shown in Table 1. These questions were organized into a hierarchical structure, as outlined below.

- **Pedagogical Objectives:** questions that evaluate the educational content's clarity, progression, and effectiveness.
- **Cultural Representation:** indicators examining cultural elements' authenticity, integration, and impact.
- **User Experience:** questions focused on usability, engagement, and technical quality.

4.2.4 Justification and relevance of the dimensions

The convergence of dimensions enables an in-depth analysis of digital games' effectiveness as teaching tools, preserving intangible heritage, and providing interactive experiences. This approach ensures a balance between learning, sociocultural identity, and accessibility.

- **Educational Dimension:**
  The educational dimension is grounded in the ability of serious games to promote meaningful learning and develop cognitive, critical, and reflective skills. Studies such as those by [Alves, 2019] highlight that digital games facilitate the transposition of abstract concepts into concrete experiences, thereby favoring the construction of knowledge through active experimentation. This concept aligns with [Gee, 2003], who emphasizes digital games as learning ecosystems in which problem-solving and adaptation to progressively challenging tasks foster the internalization of knowledge.

  To evaluate this dimension, the assessment form integrates the **PAJDE** model [de Souza Santos, 2021], which provides guidelines for curricular alignment, emphasizing pedagogical progression and clarity of instructional objectives.

  Applied to *IsoPuzzle*, this approach seeks to examine the effectiveness of supporting the transmission of mathematical content, such as geometric transformations, and how the game promotes interdisciplinary learning, establishing connections between mathematical concepts and Adinkra iconography [Dutra and Maciel, 2024; Quarcoo, 1994; Willis, 1998].

  A **40%** weight was assigned to the educational dimension, justified by the fact that, in serious games, the transmission of knowledge is the central goal and the foundation upon which the other evaluative dimensions are structured. Studies in instructional design and game-based learning emphasize that a well-structured pedagogical approach, with logical progression and continuous feedback, is crucial for the effectiveness of the teaching-learning process [Prensky and Thiagarajan, 2007; Gee, 2003].

- **Cultural Dimension:**
  Incorporating legitimate cultural references in serious games enhances the construction of a more authentic, engaging, and impactful interactive experience. The literature highlights that narratives based on sociocultural diversity expand player immersion and promote the development of inclusive and appropriately contextualized perspectives [Silveira, 2016; Oliveira *et al.*, 2016; Rizvic *et al.*, 2019]. The evaluative model used in this

study meets this demand by structuring a specific analytical criterion to measure the coherence and depth of the cultural approach in the game.

The Adinkra symbolism used in *IsoPuzzle* illustrates this integration by connecting mathematical concepts to an African worldview, adding a narrative component that emphasizes the importance of understanding diverse epistemologies [Titus and Ng'ambi, 2023; Randle, 2024]. To avoid reductionism or superficial approaches, this dimension in the model examines the presence of cultural elements, their interpretive depth, and their impact on the construction of knowledge. Thus, the cultural dimension receives a weight of **30%** in the evaluation, allowing us to assess whether the educational game acts as an instrument for disseminating collective memory and valuing sociocultural heritage.

- **UX Dimension (User Experience)**
  User experience (*UX*) plays a decisive role in the adoption and effectiveness of educational games, directly influencing immersion, navigability, and adaptability to the different needs of players [Borges *et al.*, 2019; Rizvic *et al.*, 2019]. A game may be pedagogically structured and culturally enriching, but its effectiveness will be compromised if the interaction is not intuitive or limited by accessibility barriers.

  The evaluation form incorporates assessment metrics based on the **IAQJEd** [Coutinho, 2017] to measure ease of use, cognitive ergonomics, and the fluidity of interactions. Models like *AttrakDiff* [Hassenzahl *et al.*, 2008] and SUS, as applied in the study by [Pereira *et al.*, 2023], enable a refined analysis of the aesthetic and functional attributes of the game, providing a broader understanding of the quality of the user experience. In *IsoPuzzle*, these metrics are crucial to ensure that the interface provides an intuitive interaction between players and the pedagogical and symbolic elements.

  Moreover, [Hounsell and Silva, 2021] emphasizes that digital accessibility should be considered transversally, ensuring that educational games are designed to meet the needs of diverse user profiles, including different age groups and levels of technological familiarity. This factor is essential in the case of *IsoPuzzle*, as the target audience may include students from diverse socioeconomic backgrounds. Thus, the *UX* dimension is given a weight of **30%** in the model, ensuring that interactivity and usability are analyzed from an inclusive perspective.

4.2.5 Practical Application to the IsoPuzzle Game

The practical evaluation of the *IsoPuzzle* was conducted with 33 participants[5], consisting of students from the Computer Science course at the Institute of Informatics at UFG (Federal University of Goiás). Each evaluation session lasted 45 minutes and began with an explanatory tutorial that thoroughly presented the game's mechanics, main objectives, and the use of interactive features, ensuring a minimum level of understanding for effective interaction with the tool.

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[5]Participants consented to participate by signing a free and informed consent form (TCLE).

Table 1. Questions for the Evaluation Questionnaire of the *IsoPuzzle* Game. Source: Authors.

#	Dimension	Question
1	Educational	Did the game contribute to your understanding of geometric transformations (translation, rotation, and reflection)?
2	Educational	Did IsoPuzzle facilitate your understanding of isometric geometry concepts throughout the levels?
3	Educational	Did the game balance the explanation and application of geometric transformations in the proposed challenges?
4	Educational	After playing IsoPuzzle, do you feel you better understand geometric transformations?
5	Educational	Does the game motivate you to continue playing to learn more about geometric transformations?
6	Educational	Do the content and challenges of the levels in IsoPuzzle maintain interest in mathematical and cultural learning?
7	Cultural	Did the presentation of Adinkra symbols (Ashanti culture) increase your interest in African cultural content?
8	Cultural	Were the connections between cultural elements and geometric content clear, and did they help understand the cultural context?
9	Cultural	Do you consider the game interesting and respectfully represents African culture?
10	Cultural	Is the representation of Adinkra symbols clear, visually appealing, and contributes to cultural understanding?
11	UX	Are translation, rotation, and reflection mechanics well-integrated and easy to use?
12	UX	Do the game controls respond well and precisely to your actions?
13	UX	Were the instructions on how to play and perform geometric transformations sufficient and clear?
14	UX	Do the functionalities to move the pieces and solve the puzzles work without difficulties?
15	UX	Did you encounter technical issues when using the controls?
16	UX	Describe the technical issue encountered when using the controls.
17	UX	Do the visual elements (colors, graphics, and layout) contribute to an enjoyable and educational experience?
18	UX	Is the game interface organized and allows easy navigation between different levels?
19	UX	Does the sound experience (music and effects) enhance immersion in the game and make it more enjoyable?
20	UX	Did you experience any difficulties or discomfort with the graphical interface?
21	UX	Describe the difficulty or discomfort with the graphical interface.
22	Impact and Satisfaction	Do you consider the game fun and interactive?
23	Impact and Satisfaction	Is the difficulty level of the game appropriate and encourages progress?
24	Impact and Satisfaction	Do you believe the game could be useful for other students in learning geometry?
25	Impact and Satisfaction	On a scale of 1 to 5, how would you rate your overall experience with the game?
26	Impact and Satisfaction	Which aspect of the game caught your attention the most?
27	Impact and Satisfaction	What improvements would you suggest to increase the game's educational value?
28	Impact and Satisfaction	Additional comments.

Following the preliminary session, participants explored the game in a structured setting, where trained observers closely observed their actions. During these sessions, a comprehensive record was kept of strategies employed to solve puzzles, any technical challenges encountered, and behavioral patterns exhibited. These data were instrumental in qualitatively analyzing the game's usability and users' experience.

Subsequently, the evaluation form was applied, as demonstrated in Table 1. The data from the questionnaire and the observations were integrated to provide a comprehensive view of the strengths and areas for improvement of the *IsoPuzzle*. This evaluative process, combined with quantitative and qualitative methods, helped identify opportunities for refinement to guide future adaptations and enhancements to the tool.

4.2.6 Data Collection

The data was collected, structured, and combined, ensuring that the different dimensions were analyzed holistically. The questionnaire designed to assess the three focus dimensions contains 28 questions, structured as follows:

- **Likert Scale Questions:** 21 questions structured within a scale ranging from 1 to 5.
- **Binary Response Questions (Yes/No):** Two specific questions (15 and 20) ask for simple responses to identify the occurrence of technical issues or difficulties with the graphical interface.
- **Conditional Open-ended Questions:** Questions 16 and 21 are triggered if participants answer "yes" to questions 15 and 20, respectively, allowing for further de-

tails on technical problems or discomfort with the graphical interface.
- **General and Optional Open-ended Questions:** Three questions (26, 27, and 28) provide space for open feedback, such as "What aspect of the game caught your attention the most?", "What improvements would you suggest to enhance the game's educational value?", and "Additional comments". These questions are designed to capture more subjective and exploratory perceptions.

The 21 Likert scale questions provide a consistent quantitative perspective on the evaluated dimensions. In contrast, the open-ended questions and direct observations offer qualitative insights to complement the data collection, exploring subjective perceptions of the tool's pedagogical integration, cultural representation, and usability. In addition to the general questions mentioned in the structured questionnaire, these questions provide opportunities for participants to offer detailed insights into specific issues, such as controls or game mechanics. This integrated approach facilitates a comprehensive and nuanced examination of the participants' experience with the educational tool.

4.2.7 Data Analysis and Interpretation

The data analysis process was conducted in a systematic and structured manner. The objective was to explore, validate, and interpret the results, ensuring scientific rigor and providing a detailed view of the participants' interactions with the *IsoPuzzle* game.

Quantitative Analysis Quantitative analysis was employed to calculate basic statistical metrics, such as mean and

standard deviation, from the Likert scale responses (1 to 5). These metrics were essential for evaluating the consistency and general perception of the participants regarding the educational, cultural, and UX dimensions. The final scoring formula was developed to weigh the contribution of each dimension. This step aims to objectively quantify the specific contributions of each dimension to overall game performance, thereby directly linking the data to the study's objectives.

- **Calculation of Basic Statistical Metrics:**

  - **Mean:** Represents the general perception of the participants regarding each dimension (educational, cultural, and UX).
  - **Standard Deviation:** Identifies the consistency or variability in the responses.

FS (%) =

$$\left(\frac{W_E \cdot M_E + W_C \cdot M_C + W_{UX} \cdot M_{UX}}{W_E + W_C + W_{UX}} \right) \times \frac{100}{5} \tag{1}$$

where:

- W_E: Weight assigned to the Educational dimension (0.40 or 40%).
- M_E: Mean of the responses for the Educational dimension.
- W_C: Weight assigned to the Cultural dimension (0.30 or 30%).
- M_C: Mean of the responses for the Cultural dimension.
- W_{UX}: Weight assigned to the UX dimension (0.30 or 30%).
- M_{UX}: Mean of the responses for the UX dimension.
- The factor $\frac{100}{5}$ adjusts the result from the 1-to-5 scale to the 0-to-100 percentage scale.

This approach enables the weighting of specific contributions from each dimension in the overall game evaluation, reflecting the pedagogical, cultural, and user experience objectives.

Final Evaluation Metric For the final evaluation stage, a measurement scale was created based on the principles outlined by DeVellis and Thorpe [2021], which emphasize the importance of clearly defining the constructs of interest and the appropriate response format. This scale was developed to assign values to the sum obtained in Equation (1), following the numerical classification detailed in Table 2.

Table 2. Final Evaluation Scale of the Developed Game. Source: Authors.

Interval (%)	Classification and Interpretation
90% to 100%	**Excellent:** The game fully meets the educational, cultural, and UX objectives, with high potential for replication in various contexts.
75% to 89%	**Very Good:** The game performs well in all evaluated dimensions, with minor adjustments needed for optimization.
60% to 74%	**Good:** The game meets most of the evaluated objectives, but there are significant areas for improvement.
50% to 59%	**Satisfactory:** The game performs moderately, requiring adjustments in several dimensions to achieve greater effectiveness.
Below 50%	**Unsatisfactory:** The game does not meet the expected objectives, requiring structural revisions and substantial improvements.

The adopted strategy integrates quantitative data and qualitative analyses, providing an accessible interpretation for researchers and developers and guiding improvements in the design and application of the game.

Qualitative Analysis The qualitative analysis was structured following the thematic categorization principles described by [Braun and and, 2006]. Thematic codes were created to organize the open-ended responses, categorizing perceptions into areas such as technical issues, cultural engagement, and pedagogical impact. This process involved:

- **Thematic Categorization:** Open-ended responses were organized into broad categories, such as: Technical issues (e.g., crashes or unresponsive controls); Cultural engagement (e.g., impact of Adinkra symbols and cultural authenticity); and Pedagogical impact (e.g., learning geometric transformations and clarity of educational objectives).
- **Coding:** Each comment was assigned to a thematic category to facilitate the identification of patterns and divergences. For example, comments about "difficulties with controls" were grouped under "Technical issues.", and Observations about "authentic cultural representation" were categorized under "Cultural engagement."

This step connected the qualitative data with the quantitative metrics, enriching the interpretation of the results.

Data Triangulation Data triangulation was employed as a central approach to validate the findings, aiming to obtain a more comprehensive, reliable, and interconnected analysis. This technique enabled the integration of quantitative results, qualitative insights, and

direct observations.

The process was structured in complementary stages.

- **Comparison between data sources:** The quantitative responses (Likert scales) were contrasted with qualitative perceptions. For example, low scores in the UX dimension were correlated with comments on technical issues, such as control delays and navigation difficulties. Similarly, qualitative reports that highlighted the authenticity of the Adinkra symbols and their effective pedagogical integration contributed to high scores in the cultural dimension.
- **Cross-validation:** Observational data recorded during the interaction sessions with *IsoPuzzle* confirmed the perceptions reported in the questionnaires. Praise for the clarity of the pedagogical mechanics was validated by records of active participant engagement during problem-solving tasks.

A comparison of Likert scale scores and the qualitative reports revealed significant correspondences and divergences. For instance, negative assessments in the UX dimension were elucidated by direct observations that identified specific usability challenges. Conversely, reports on the effectiveness of feedback mechanics and the authenticity of integrated cultural elements reinforced positive perceptions in the educational and cultural dimensions.

This integrative approach highlighted important nuances that would be difficult to capture in isolation, showcasing areas of excellence, such as instructional clarity and cultural authenticity, as well as critical limitations, such as technical issues and the need for improvements in the graphical interface. Triangulation also minimized potential biases, ensuring that the results reliably reflected the participants' interactions with the evaluative model and the game being analyzed. This practice was essential for grounding solid and relevant recommendations for improving *IsoPuzzle* and applying evaluative methodologies in educational and cultural contexts.

Based on the outlined evaluation methodology, the following section presents the results obtained from the practical application of the evaluation form in the context of *IsoPuzzle*, with detailed analyses highlighting theoretical and practical implications for ethno-pedagogical serious games.

5 Results and Discussion

This section presents the results of evaluating the game *IsoPuzzle*, structured according to the educational, cultural, and user experience (UX) dimensions. The analysis of the data, based on the **33 responses** collected from different participants, revealed both the strengths of the game and its limitations, providing valuable insights for improving the game as an ethno-pedagogical tool.

The overall results indicated a final score of **77.62%**, classifying the game as **Very Good**, according to the

adapted scale by [Connolly *et al.*, 2012]. This classification reflects the effectiveness of *IsoPuzzle* in achieving pedagogical, cultural, and technical objectives, as illustrated by the mean scores for each dimension presented in Figure 7. However, the standard deviations for each dimension, presented in Figure 8, highlight areas that require specific improvements to enhance the user experience and strengthen the game's pedagogical integration and cultural relevance.
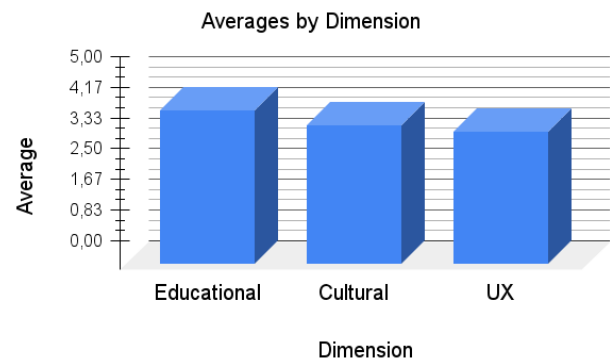

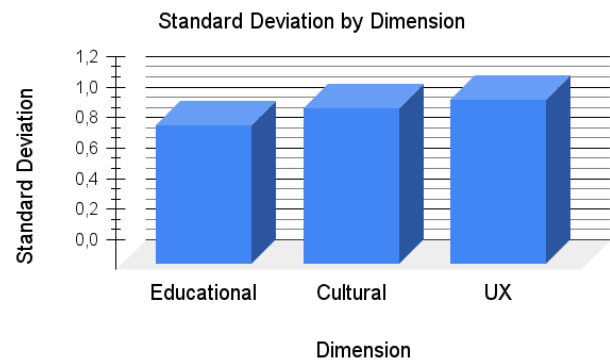**Figure 7.** Mean Scores by Dimension. Source: Authors.

Figure 8. Standard Deviation Graph by Dimension. Source: Authors.

5.1 Educational Dimension

The data on the educational dimension were analyzed, highlighting IsoPuzzle's impact on the assimilation of mathematical concepts, with a particular emphasis on geometric transformations. Participants evaluated the clarity and progression of the proposed activities, as well as how the game stimulates knowledge construction through continuous interaction and the structured resolution of challenges.

Key Findings The quantitative data indicated an overall average of **4.16** for questions related to the educational dimension, with a standard deviation of **0.91**. These values reflect the consistency in participants' positive perceptions regarding the clarity of geometric concepts. The logical progression of levels and the interactive feedback were particularly praised, reinforcing the game's effectiveness in promoting active learning. Suggestions for more visual tutorials and practical examples

that connect mathematical concepts to daily life highlight clear opportunities for improvement to increase the learning experience's applicability and relevance. Below are some highlighted points.

– **Conceptual Clarity:** The presentation of mathematical concepts was positively evaluated by many participants, highlighting the logical progression of levels as an important factor in facilitating learning.
– **Effectiveness of Feedback:** Qualitative comments praised the feedback provided during the experience, which contributed to understanding and applying the concepts of geometric transformations.

Limitations and Suggestions Despite the positive results, several areas were identified that could be improved.

– **Visual Tutorials:** Participants suggested the inclusion of more interactive and visual tutorials to demonstrate geometric transformations before their practical application. This approach could increase accessibility and engagement, especially for novice players.
– **Connection with Everyday Applications:** The inclusion of practical examples contextualizing geometric transformations in everyday situations, such as in architecture, engineering, or design, was recommended to increase the relevance and applicability of the learning.

5.2 Cultural Dimension

The cultural dimension analysis highlighted the relevance of *IsoPuzzle* in increasing participants' interest in Ashanti heritage, mainly through the use of Adinkra symbols. The authenticity and coherence of these elements within the educational context were emphasized.

Key Findings Quantitative data indicated an overall average of **3.78** for questions related to the cultural dimension, with a standard deviation of **1.02**, highlighting the positive impact of the game in sparking interest in Ashanti culture and Adinkra symbols. About **78%** of the participants reported an increased interest in African culture after the experience. However, a need for greater narrative contextualization was identified, with the inclusion of short stories or more detailed explanations about the cultural meanings of the symbols, strengthening the connection between pedagogical and cultural aspects. Below are some highlighted points:

– **Authentic Representativity:** The Adinkra symbols were widely recognized as authentic and well-represented, reinforcing the connection between cultural narrative and pedagogical goals.
– **Positive Cultural Impact:** Qualitative comments highlighted that interaction with cultural elements

promoted empathy and intercultural understanding, contributing to a deeper learning about the historical and social relevance of the symbols.

Limitations e Suggestions Despite the significant contributions, areas that could be improved were identified:

– **Cultural and Pedagogical Connection:** Many participants noted the need for a clearer connection between cultural elements and mathematical challenges. Short narratives or historical explanations could contextualize the Adinkra symbols and enrich the learning experience.
– **Narrative Enrichment:** Recommendations included introducing interactive stories, animations, or even mini-games that explain the cultural and historical meaning of the symbols before the start of each level, making the experience more immersive.

Cross-Relations with Other Dimensions The analysis highlighted significant intersections between the cultural and educational dimensions. For example, the Adinkra symbols were described as elements that connect geometric concepts to the cultural context, enriching the pedagogical narrative and promoting greater engagement with the proposed challenges.
Improvements in cultural integration can create more meaningful, inclusive, and empathetic learning experiences for players, strengthening the game's role as an ethno-pedagogical example.

5.3 User Experience (UX) Dimension

The UX dimension showed more significant variability in the evaluations, with an overall mean of **3.61** and a standard deviation of **1.08**, reflecting divergent perceptions among participants. While some praised the simplicity of the interface and ease of navigation, inconsistencies related to usability, control responsiveness, and technical issues were identified as critical areas that negatively impacted the user experience.

Key Findings The data highlighted the following aspects:

– **Interface and Navigation:** Approximately **65%** of the participants positively mentioned the simplicity of the interface and ease of navigation. However, recurring criticisms highlighted issues with visual clarity and the organization of graphical elements, suggesting the need for a more intuitive redesign.
– **Soundtrack:** Some players praised the soundtrack for the immersion it provided, but recommended variations that align with the progression of the levels to reduce monotony during long gaming sessions.

– **Technical Issues:** Reports of delays between levels, difficulty in selecting pieces, and failures in the responsiveness of controls were identified as factors that compromised the fluidity of the experience.

Limitations and Suggestions   The identified limitations highlight critical areas for improvement in the UX dimension:

– **Controls and Responsiveness:** Approximately **18%** of the participants reported technical issues related to the responsiveness of the controls, including delays and difficulty in executing expected actions. Improvements in this aspect are essential to provide a smoother experience.
– **Improvements in Graphic Interface:** Suggestions included reorganizing the graphical elements to increase clarity and reduce interruptions during screen transitions. A cleaner design tailored to the target audience was widely requested.
– **"Undo Move" Functionality:** Several participants suggested adding a functionality to undo incorrect moves, which would make the game more accessible and reduce frustration caused by unintentional errors.
– **Animations and Visual Feedback:** Strengthening the visual feedback of actions, such as animations that indicate the impact of a command, was pointed out as a desirable improvement.

Cross-Dimensional Relationships   The technical issues in UX also impacted the educational dimension, particularly when unresponsive controls hindered the practical application of geometric concepts. Furthermore, the visual and interactive experience was mentioned as a key element in reinforcing cultural integration, highlighting the need for a design that directly connects the cultural aspects to the game context.

These findings emphasize that, while the basic interface and controls are functional, significant adjustments are necessary to enhance usability and overall experience. Investing in a more robust and accessible design, as well as improvements in control responsiveness and auditory immersion, could transform *IsoPuzzle* into a more effective tool for diverse audiences.

5.4   Technical Aspects

In addition to the core dimensions, technical issues emerged as a significant concern, directly impacting the user experience. The data indicated that these issues should be prioritized to ensure greater accessibility and operational reliability of the game.

The technical challenges identified were particularly evident in compatibility with devices of varying specifications. Issues such as control responsiveness failures and incompatibility with different screen resolutions suggest the need for additional testing and adjustments in the game's technical design. These points are especially

relevant in educational contexts where access to modern devices may be limited.

– **Freezes and Errors:** Reports of freezing and unresponsiveness on specific devices indicate the need to optimize the game's technical stability. These issues were particularly notable in higher-level stages, where the processing load is likely to be greater.
– **Compatibility:** Participants reported difficulties when attempting to play on devices that do not run the Android operating system, highlighting the importance of ensuring the game is adaptable to various hardware configurations and operating systems. The lack of consistent support for diverse devices was a limiting factor.
– **Resolution and Interface:** Some participants mentioned issues with screen scaling, where graphical elements were cut off or displayed improperly, making navigation and interaction with the game more difficult.

These technical aspects ensure the game's accessibility across various educational contexts and devices. Investing in technical optimizations and conducting extensive testing across multiple devices can help mitigate these issues and enhance the overall user experience.

5.5   Perspectives for Improvement

Based on the results obtained, this study suggests several directions for exploration to enhance both the game and the evaluation methodology. The main recommendations include:

– **Enhancement of Evaluation Indicators:** Expand the evaluation criteria to deepen the analysis of the interactions between the educational, cultural, and user experience dimensions, ensuring a more detailed understanding of the game's impact on learning and artistic perception.
– **Integration of Collaborative Mechanics:** Develop game modes that encourage solving challenges as a team, promoting knowledge exchange among players and stimulating strategic thinking and collective work.
– **Inclusion of Narrative Elements:** Introduce stories and characters that contextualize geometric challenges within cultural narratives, providing additional cognitive support and making learning more meaningful.
– **Digital Platforms for Monitoring:** Create tools that allow tracking player progress in real-time, using interactive *dashboards* to assist educators in adapting pedagogical strategies according to students' performance.
– **Optimization for Accessibility:** Implement resources such as screen readers, descriptive subtitles, and visual adjustments to expand the game's reach and ensure its use by audiences with different needs, including people with visual impairments or motor difficulties.

- **Expansion to Other Cultures:** Apply the methodology developed in *IsoPuzzle* to games that represent other cultural traditions, enabling the creation of educational experiences contextualized in different historical and symbolic perspectives.
- **Contextualized Events and Challenges:** Incorporate thematic challenges linked to holidays or specific cultural events, making learning more dynamic and connected to the players' experiences.
- **Longitudinal Studies:** Investigate the effects of continuous game use on the retention of mathematical knowledge and the development of intercultural competencies, analyzing long-term impacts.
- **Application in Educational Public Policies:** Explore the model's potential to support educational guidelines that promote serious games in school curricula, strengthening teaching practices that value interdisciplinarity and cultural diversity.

6   Conclusion

When revisiting the key findings from the implementation and evaluation of *IsoPuzzle*[6], its relevance as an educational tool focused on teaching geometric transformations stands out, as it effectively integrates mathematical concepts with representative cultural elements. The project presents structured challenges while providing a learning experience grounded in interdisciplinarity, promoting understanding of mathematical concepts and the appreciation of African cultural elements.

The results from the evaluation suggest that *IsoPuzzle* offers an interactive experience that integrates mathematical abstraction with visual representations, thereby capturing the players' interest. Adinkra symbolism enhances the connection between users and cultural content, fostering a deeper appreciation of its symbolic elements. However, the evaluation of the user experience highlighted challenges regarding the clarity of instructions and the accessibility of the interface, revealing opportunities for adjustments to make navigation more intuitive.

Statistical metrics supported the reliability of the collected data. The educational dimension presented a standard deviation of **0.91** and an overall average of **4.16**, indicating consistent responses regarding the game's pedagogical adequacy. The cultural dimension had a standard deviation of **1.02** and an overall average of **3.78**, reflecting variation in perceptions about the integration of cultural heritage. The user experience dimension presented the highest standard deviation (**1.08**) and an overall average of **3.61**, signaling more significant differences in the evaluations of the interface and gameplay. Additionally, it was observed that variations in the technical quality of the devices used by participants influenced the experience, highlighting the need for op-

timization across multiple platforms.

The evaluative methodological approach, which combined quantitative and qualitative methods, proved effective for evaluating the game. However, improvements in data collection and analysis processes could enhance accuracy and facilitate the replication of the study in other contexts and with other serious ethno-pedagogical games.

Integrating mathematics and culture in *IsoPuzzle* can provide a distinctive educational experience that aligns with contemporary demands for teaching methodologies that are more dynamic, inclusive, and connected to students' realities.

The results reinforce the importance of evaluative methodologies that go beyond technical analysis and incorporate sociocultural and pedagogical aspects. Adopting interdisciplinary strategies and exploring new possibilities in the design of interactive experiences represents a promising path for enhancing educational practices and solidifying serious games as practical tools for supporting teaching and promoting cultural diversity among young people.

Declarations

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Authors' Contributions

The first author is a master's student in Computer Science, whose dissertation is directly aligned with the research presented in this article. The second author is a researcher in Mathematics Education, and the third is a specialist in African Culture. The fourth and fifth authors are senior researchers who supervised the project, guiding all aspects of the work, including methodological refinements and critical revisions.

Availability of data and materials

The raw data from the questionnaire — comprising 33 anonymized responses — are publicly available for audit and verification purposes at the following link: **"Link here"** (Last access on 03 July 2025), also available at the paper's publication page. At the publication time, the source code of the game is not publicly available due to technical constraints.

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[6]The game is available for download at https://sankoffa.itch.io/isopuzzle. Access on 20 June 2025. Compatible with Android and Windows systems.

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