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Instructional Design Development of Mahilung Mobile Learning Based on the 4-D Model as an Ethno-Edugames Framework for Dayak Cultural Literacy

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ABSTRACT

The implementation of cultural literacy in elementary schools still tends to be content-centric and has not been systematically integrated into digital instructional design, particularly in the context of Dayak culture in Central Kalimantan. This study aims to develop a Mahilung Mobile Learning instructional design based on the 4-D model (Define, Design, Develop, Disseminate) as an ethno-edugames framework in strengthening Dayak cultural literacy in elementary school students. The study uses a Research and Development (R&D) approach with a mixed-methods design. The definition stage includes needs analysis, student characteristics, and curriculum review to identify Dayak cultural values relevant to Theme 8 "Our Friendly Environment." The design stage includes mapping cultural values into learning objectives, game mechanics, and assessment components. The development stage is carried out through the development of an Android-based application prototype that can be accessed offline, equipped with interactive audio-visual materials, exercises, and ten mini-games based on true-false validation with a scoring system as part of the gamification strategy. Expert validation and limited trials were conducted to refine the design. Qualitative data were analyzed thematically, while quantitative data were analyzed using Likert scores to assess feasibility and user response. The results of the study produced a processual ethno-edugames design framework that structurally integrates Dayak cultural values into digital

game-based learning. This research contributes to the development of a contextual, adaptive, and applicable culture-based instructional design model in primary education.

Keywords
Dayak Cultural Literacy
Ethno-Edugames
Instructional Design
Mobile Learning

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Introduction

Literacy is an essential competency that is a prerequisite for 21st-century life skills and an important indicator in the development of sustainable human resource quality. UNESCO emphasizes that literacy is the foundation of lifelong learning and a key instrument in sustainable human development [1]. In line with the World Economic Forum report, 21st-century education demands the development of three main domains: fundamental literacies, thinking and problem-solving competencies, and character qualities [2]. Fundamental literacy encompasses not only reading and numeracy skills, but also literacy in science, information and communication technology, finance, and cultural and civic literacy.

In the context of a digital society, cultural and civic education that aligns with the characteristics of the millennial generation plays a crucial role in shaping students' critical and selective thinking skills in the flow of digital information [3]. The widespread spread of hoaxes and hate speech demonstrates the urgency of strengthening cultural and civic literacy as a foundation for inclusive and responsible character building. Cultural literacy not only supports the learning process but also serves as adaptive capital for individuals to interact harmoniously in a multicultural society [4]. Therefore, strengthening cultural literacy needs to begin at the elementary level to foster sensitivity, openness, and the ability to constructively address diversity.

However, the state of cultural literacy in Indonesia still faces significant challenges. The numerous cases of discrimination and SARA issues that continue to emerge in public spaces reflect the suboptimal internalization of diversity values [5]. Data from the National Commission on Human Rights (Komnas HAM) in 2021 showed that 27.8% of respondents had experienced or witnessed discriminatory acts, indicating a lack of understanding and inclusive attitudes in society. This condition is related to individuals' limited cognitive understanding of cultural values and diversity [6]–[7]. This fact confirms that strengthening cultural literacy through systematic and contextual learning design is an urgent need in the national education system.

At the implementation level, the implementation of cultural literacy in several elementary schools has not been comprehensively integrated. Local cultural material is still predominantly presented textually in thematic books with minimal visual support and interactive approaches [8]. The results of a review of the Student Book Theme 1 The Beauty of Togetherness show that the cultural dimension has not been systematically accommodated in the learning design, even though it is included in the Basic Competencies [9]. Cultural literacy tends to be partial and has not been designed as an integrated conceptual and practical framework. The limitations of representative visual media and the lack of local culture-based teaching materials also make it difficult for teachers to relate the material to the context of students' lives [8], [10]. As a result, cultural values are often perceived as abstract concepts that lack meaning for students.

This problem is further complicated in the context of the local culture of Central Kalimantan, where Dayak folklore and cultural values are traditionally passed down orally [11]. Changes in the characteristics of the digital generation have made these conventional transmission patterns increasingly less effective in reaching today's students. In fact, Dayak cultural literacy encompasses not only the recognition of cultural symbols but also an understanding of value systems, local wisdom, social practices, and a philosophy of life that emphasizes togetherness, balance with nature, and respect for ancestors. Recent research shows that integrating local Dayak culture into learning can strengthen students' identity and build character based on the values of cooperation and social responsibility [12]–[14]. Therefore, strengthening Dayak cultural literacy in elementary schools is strategic in building the identity of the younger generation in the digital era.

This condition demands innovation in learning design that is not only oriented towards delivering material, but also towards transforming learning experiences into contextual and participatory ones. The integration of game elements into learning media has been proven to increase student engagement and motivation [15]–[17]. The ethno-edugames approach allows local cultural values to be structurally integrated into game mechanics, not simply as learning content. When developed through a mobile learning platform, this approach provides a learning experience that is flexible, easily accessible, and in line with the characteristics of the digital generation.

Based on these needs, this research developed Mahilung Mobile Learning, a learning application whose name is taken from the Banjar language meaning “to maintain” [18]. Mahilung is designed to maintain cultural values, character, and environmental awareness through the integration of Dayak values in learning Theme 8 Our Friendly Environment. The

development was carried out using the 4-D instructional design model (Define, Design, Develop, Disseminate) to ensure systematic and structured design.

Although extensive research on mobile learning and game-based learning has been conducted, studies specifically integrating 4-D instructional design with an ethno-edugames framework to strengthen Dayak cultural literacy at the elementary school level are still limited. Previous studies generally position culture as learning content, rather than as a structural element in digital instructional design. Therefore, this study aims to develop a Mahilung Mobile Learning instructional design based on the 4-D model as an ethno-edugames framework in strengthening Dayak cultural literacy in elementary schools. The novel contribution of this study lies in the systematic integration of the 4-D instructional design model, mobile learning platforms, and Dayak cultural values within a single contextual, adaptive, and sustainable digital learning framework.

Material and Methods

This research is a research and development (R&D) that aims to develop an instructional design for Mahilung Mobile Learning based on the 4-D model (Define, Design, Develop, Disseminate) proposed by Thiagarajan. This research does not only focus on the development of media products, but on the construction of an ethno-edugames-based instructional design that systematically integrates Dayak cultural values into thematic learning in elementary schools. The approach used is a mixed-methods design with the integration of qualitative and quantitative data to obtain a comprehensive picture of the development process and the quality of the resulting design.

In the define stage, a needs analysis was conducted through interviews with fifth-grade teachers, analysis of student characteristics, and curriculum review to identify the integration of Dayak cultural values relevant to Theme 8 “Our Friendly Environment.” Literature studies on cultural literacy and the ethno-edugames approach were also conducted to strengthen the conceptual basis of the design.

The design phase included the development of an instructional design, including mapping learning objectives, integrating Dayak cultural values into game mechanics, developing a media flowchart, and developing a storyboard. The learning components were designed in the form of interactive audio-visual materials, HOTS-based practice questions, and ten mini-games with a true-false validation system and scoring as part of the gamification strategy.

In the development phase, an Android-based Mahilung prototype was developed that could be accessed offline. Design validation was conducted by two experts (a material expert and a media expert) to assess content suitability, cultural value integration, and technical aspects of the design. A limited trial involved six teachers and 31 fifth-grade students from two

elementary schools in Palangka Raya City, selected purposively. The research instruments included an expert validation sheet, teacher and student response questionnaires, and interview and observation guidelines.

The dissemination stage in this research was carried out on a limited basis as the final part of the 4-D development model. Dissemination was carried out through two forms of activities, namely (1) registration of Intellectual Property Rights (IPR) for the Mahilung Mobile Learning application as a form of legal protection for the developed innovation product, and (2) product socialization to elementary school teachers in Palangka Raya City.

The socialization activities were conducted through live demonstrations of application usage, explanations of key features, ethno-edugames-based learning flows, and integration of Dayak cultural values into thematic learning for Theme 8 "Our Friendly Environment." This stage aimed to introduce the product to potential users and obtain initial feedback regarding its potential implementation in an elementary school context. Dissemination in this study was limited and focused on the introduction and continued use of the product, rather than on testing its effectiveness on a large scale.

The subject of development in this research is the instructional design of Mahilung Mobile Learning, while the research objects include design quality and the integration of Dayak cultural values in game-based learning structures.

Results

The development of Mahilung Mobile Learning as an ethno-edugames-based media instructional design was carried out through the 4-D model stages, namely define, design, develop, and disseminate. This results section presents the findings at each stage of development that emphasize the process of constructing instructional design in integrating Dayak cultural values into thematic learning for fifth grade elementary school.

A. Define Phase

The define phase began with a needs analysis through interviews, classroom observations, and questionnaires distributed to 33 students and two fifth-grade teachers at two elementary schools in Palangka Raya City. Observations showed that thematic learning was still dominated by textbooks and student worksheets without the support of contextual, culturally relevant digital media. The learning media used tended to be general and did not explicitly integrate Dayak cultural values into the learning structure. Teachers also reported limited learning resources that could link thematic material to the local cultural context, resulting in cultural literacy still being delivered narratively and not internalized through meaningful learning experiences.

Analysis of student characteristics shows that most students are accustomed to using mobile devices in their daily activities and have a strong interest in game-based applications. Students are more responsive to interactive visual-audio media than to presentations in long text formats. However, there is a lack of mobile learning media that can be accessed offline and systematically integrate Dayak cultural values into thematic learning contexts. This situation highlights a gap between the characteristics of the digital generation and the availability of culturally relevant learning media.

The questionnaire results indicate a significant need for the development of mobile learning-based learning media that are contextual and adaptive to school conditions. Ninety-seven percent of students and 75% of teachers expressed strong approval for the development of the Mahilung application as a mobile learning medium for ethno-edugames. These findings indicate that Dayak cultural literacy learning has not been systematically integrated into existing digital learning designs and requires an instructional design approach that combines local cultural values, game mechanics, and gamification systems within a structured learning framework.

In addition, the curriculum analysis of Theme 8 “Our Friend Environment” identified the potential for cross-subject integration, including Indonesian, Science, Social Studies, Civics, and Arts and Culture. The curriculum resulted in a mapping of learning indicators, which were then linked to Dayak cultural values such as Handep Hapakat (togetherness), Pintar Tuntang Harati (intelligent and virtuous), and ecological awareness relevant to the context of environmental conservation. This stage resulted in the formulation of instructional design needs that place Dayak cultural values as structural elements in the design of Mahilung Mobile Learning.

B. Design Phase

The design stage focuses on the preparation of the instructional design architecture of Mahilung Mobile Learning by integrating Dayak cultural values into the thematic learning structure based on ethno-edugames. The design planning is grouped starting from the general overview of the learning process using Mahilung media, preparation of the initial product design, development of flowcharts and application storyboards, to the design of mini-games as part of the gamification system.

The design workshop resulted in a learning flow consisting of three main contexts: the family environment, the school environment, and the community environment. These three contexts were chosen to represent the spaces where Dayak cultural values are actualized in students' daily lives, ensuring that learning is inseparable from local social and cultural realities.

At this stage, a content analysis was conducted on the Basic Competency (KD) indicators from the subjects of Indonesian Language, Science, Social Studies, Civics, and Arts and Crafts in

Theme 8. This analysis aims to identify conceptual competencies, skills developed, and opportunities for integration of relevant Dayak cultural values. The analysis process was carried out by examining the relationship between the material content and the principles of cultural values , such as Handep Hapakat, Pintar Tuntang Harati, and ecological awareness of the Dayak community.

The results of this analysis were then reconstructed into a digital learning scenario based on ethno-edugames. The Handep Hapakat values were internalized through activities that emphasized social cooperation and community harmony. The Pintar Tuntang Harati values were integrated into decision-making activities based on conceptual understanding and moral reflection in mini-games. Meanwhile, the Dayak community's ecological awareness was manifested in environmental conservation materials and organic and inorganic waste classification activities. Thus, cultural values are not merely present as content but also become the structural foundation in the architecture of the Mahilung digital learning experience.

The reconstruction of the thematic curriculum based on Dayak cultural values in the Mahilung Mobile Learning design is presented in Table 1.

Table 1. Reconstruction of the Thematic Curriculum

No.	Subjects	Indicators analyzed	Reconstructed Dayak Cultural Values	Forms of Integration in Mahilung
1.	Indonesian	3.3–4.3 Understand and present advertising information	Pintar Tuntang Harati (intelligent and well-mannered), Belom Bahadat (ethical in communication)	Mini-games for analyzing advertising messages based on value reflection, exercises in filtering information wisely
2.	Science Education	3.8–4.9 Environmental equilibrium, single substances and mixtures	Dayak ecological awareness (human-nature harmony)	Organic-inorganic waste classification game, environmental conservation simulation based on local values
3.	Civic Education	1.4–3.4 Unity, oneness, social harmony	Handep Hapakat (cooperation), Huma Betang (living in diversity), Belom Bahadat (living in a civilized, polite manner)	Ethical choice scenarios, social decision simulations, narratives of togetherness in community life
4.	Social Studies	3.1–4.3Indonesia's geography and economic role	Dayak local identity, Handep Hapakat (Mutual Cooperation), Social responsibility	Visualization of the Central Kalimantan context, simulation of the role of the economy based on community cooperation
5.	Cultural Arts and skills	3.2–4.4 Scales, dance floor patterns, fine arts	Preservation of Dayak culture, Expression of cultural identity	Audio-visual Dayak art, identification of regional dance patterns, exploration of local fine arts in games

The thematic curriculum reconstruction in Table 1 shows that the integration of Dayak cultural values in Mahilung Mobile Learning is not done symbolically or additionally, but rather

through the transformation of curriculum indicators into a pedagogical structure based on ethno-edugames. Each learning indicator is reinterpreted within the framework of local cultural values, thus creating harmony between academic objectives and strengthening cultural identity.

The values of Handep Hapakat and Huma Betang are represented in collaborative activities and social decision-making, while Pintar Tuntang Harati is realized through reflective and analytical activities in mini-games. Dayak ecological awareness forms the basis for integrating science and environmental conservation materials. With this approach, Mahilung not only delivers thematic material but also reconstructs the curriculum into a digital learning experience that is contextual, participatory, and based on local wisdom.

The initial design of Mahilung Mobile Learning was developed through a product design workshop that resulted in an application architecture with seven main components: Start/Continue, Materials, Mini-Games, Scoring, Achievement, Option, and Exit. The Start and Continue menus function to manage user identity through name and avatar selection, while the Materials component presents thematic content in three learning contexts: family, school, and community. The main navigation structure of the application, which contains these components, is shown in Fig. 1.



Fig. 1. Mahilung Mobile Learning Main Menu Display



Fig. 2. Display of the Thematic Learning Context

These three learning contexts were developed based on the analysis of the curriculum for Theme 8, "Our Friendly Environment," and integrated with Dayak cultural values in a digital learning scenario. A representation of the three thematic learning contexts in the application interface is shown in Fig. 2.

The application's flowchart and storyboard design systematically organize the user interaction flow, from login, selection of content context, exploration of interactive audio-visual content, to evaluation through mini-games. An example of the implementation of interactive audio-visual-based materials in one learning context is shown in Fig. 3.



Fig. 3. Example of Interactive Material Display (School Environment)



Fig. 4. Scoring System and Leaderboard

The mini-games are designed as part of a gamification system that includes true-false validation-based questions with an automated scoring system. User scores are accumulated in the Leaderboard and Achievement features with four levels of achievement (Fail, Satisfactory, Good, and Excellent), creating a progressive feedback mechanism. The scoring and achievement system mechanism is shown in Fig. 4.

This structure allows for reflective, achievement-based learning while strengthening student engagement in the independent learning process. Overall, the implementation flow of learning using Mahilung Mobile Learning is visualized through the flowchart in Figure 5.

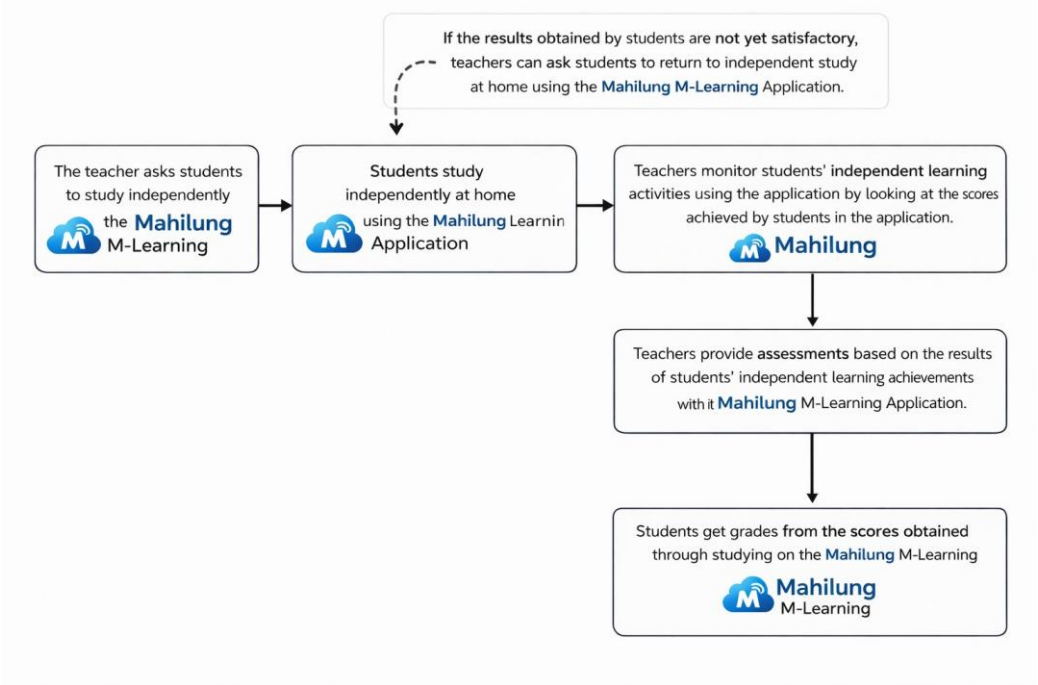


Fig. 5. Learning Process Flow

The flowchart shows that Mahilung Mobile Learning is designed as a self-paced learning system integrated with teacher monitoring and evaluation mechanisms. The process begins with the teacher directing students to learn independently using the application. Students then complete the material and mini-games, resulting in achievement scores. These results can be

monitored by the teacher as a basis for providing feedback and assessment. If achievement is not optimal, students are directed to repeat the learning process, forming a reflective and sustainable learning cycle. This flow emphasizes that Mahilung functions not only as a digital medium but as part of an instructional design that supports self-paced learning, formative feedback, and systematically strengthens cultural literacy.

The material integrated into the application covers cross-subject content, namely Indonesian (advertising), Science (single and mixed substances and environmental conservation), Civics (unity), Social Studies (geographical characteristics and economic roles), and Arts and Crafts (scales, dance floor patterns, and fine art). Validation of the material is carried out based on aspects of content quality, presentation, and language to ensure suitability with the learning objectives and characteristics of elementary school students.

C. Develop Phase

The development phase was carried out by integrating all visual, audio, and interactive system assets into an Android-based application platform. The user interface (UI) design that was prepared in the design phase was realized using vector graphics software and then integrated into Adobe Animate to build the navigation structure, transitions between slides, and a score- and achievement-based gamification system. The programming process used Action Script 3 (AS3) to organize the functionality of menus, mini-games, automatic score calculations, and progressive feedback mechanisms. This development phase resulted in the final product, the Android-based Mahilung Mobile Learning, which has undergone expert validation and systematic revision. The final product displays full integration between instructional design, Dayak cultural content, and an interactive gamification system in a single digital learning environment that can be accessed offline.

To support the learning characteristics of elementary school students, the application is equipped with multimodal features in the form of narrative text, contextual illustrations based on cultural contexts, voice-overs, and interactive sound effects. Audio integration is implemented to increase engagement and facilitate conceptual understanding, particularly for abstract topics such as single substances and mixtures, and the concept of unity in social life.

The main application interface (see Fig. 6) contains two core menus: Materials and Mini Games, which are designed to be simple and intuitive to suit the characteristics of elementary school students.

In the Materials menu, thematic content is presented in the form of narrative text, contextual illustrations, explanatory audio, and a click-through feature for visual elements. Clickable images within the materials can be clicked to display audio-visual explanations. Additionally, the app provides the following features: watching learning videos, listening to radio advertisements, playing the digital piano, and direct screen-based interaction. This

multimodal approach was developed to address the diverse learning characteristics of students (visual, auditory, and kinesthetic). Below is an example of the Material Menu display in the School Environment.



Fig. 6. Final Appearance of Mahilung Product



Fig. 7. Display of School Environment Materials

Mini-games based on Higher Order Thinking Skills (HOTS) were developed in the form of contextual case studies that encourage students to analyze social situations, consider alternative actions, and determine the right decision. This design internalizes the values of Handep Hapakat through an emphasis on cooperation and social harmony, as well as the values of Pintar Tuntang Harati through rational and reflective thinking processes. Thus, the function of mini-games is not limited to cognitive evaluation, but also as a means of character building and cultural literacy.

Additionally, cultural mini-games, such as composing lyrics to Central Kalimantan regional songs, were developed to interactively strengthen cultural literacy and appreciation of musical arts. During the revision phase, a time limit was added, the automatic feedback system was refined, and interactive features such as audio-visual aids, instructional videos, and click-through elements were enhanced. These revisions aimed to improve learning focus, student engagement, and the effectiveness of ethno-edugames-based learning experiences.

Based on validator input and the results of limited trials, several improvements were made, including: adding time limits to mini-games, optimizing the automatic scoring system and direct feedback, adding audio narration to all materials, improving navigation to make it more user-friendly, and adding multimedia features.

This revision resulted in an application that is not only substantively sound but also pedagogically and technologically robust. Product feasibility was tested through validation by subject matter and media experts using a five-level Likert-scale instrument. The material substance aspect received an average score in the very feasible category, with a feasibility index above 0.85. The media display and engineering aspects were in the feasible-very feasible category, with an average percentage above 0.80. Overall, the product's composite feasibility score was in the high feasibility category, thus meeting the criteria for testing on students.

Several validator inputs related to strengthening the local context in material visualizations, adding a variety of problem-solving-based questions, and refining the navigation to make the learning flow more reflective. Revisions included adding more representative cultural illustrations, enriching mini-games with problem-based scenarios, and restructuring the slide transition system to avoid focusing solely on score-based learning.

Limited trials were conducted in two elementary schools involving teachers and fifth-grade students. Analysis of user responses showed that the application was assessed as practical for use in limited face-to-face learning and independent learning, supports integrated cross-subject understanding, and increases learning motivation through gamification and level achievement systems. Overall, user acceptance was very good, with the majority of students showing interest in the mini-games and interactive audio features. Teachers considered the application effective as a supporting medium for thematic learning based on local culture.

Thus, the development phase resulted in a Mahilung Mobile Learning product that is substantively and technically feasible, responsive to the characteristics of elementary school students, integrates Dayak cultural values into the gamification system, and is ready for broader implementation in further research.

D. Dissemination Phase

The dissemination phase was conducted on a limited basis through Intellectual Property Rights (IPR) registration for the Mahilung Mobile Learning application as a form of protection and to strengthen the legality of the product being developed. In addition, outreach activities were conducted for elementary school teachers in Palangka Raya City through demonstrations of application use and presentations on the integration of Dayak cultural values into thematic learning.

Socialization activities demonstrated that Mahilung is viewed as a learning medium relevant to the characteristics of elementary school students and has the potential to support the strengthening of cultural literacy based on ethno-edugames. This stage marks the product's completion not only in the development stage but also in the introduction to potential users in a real-life educational context.

Discussions

The results of the study indicate that the development of Mahilung Mobile Learning based on the 4-D model is able to produce an ethno-edugames instructional design that systematically integrates Dayak cultural values into thematic learning in elementary schools. This finding is in line with the research of Ameliya et al. [19], which shows that the implementation of ethno-edugames-based applications is effective in improving creative thinking skills through the integration of local cultural contexts into game activities. This

confirms that culturally-based educational games do not only function as entertainment media, but as pedagogical strategies that strengthen high-level cognitive abilities.

The integration of Dayak cultural values in Mahilung through mini-games based on case studies, attitude analysis, and the arrangement of regional song lyrics also supports the findings of Ahyati [20] who stated that educational games based on local culture contribute significantly to the understanding of cultural literacy of elementary school students. By incorporating the values of Handep Hapakat and Pintar Tuntang Harati into decision-making scenarios and reflective activities, Mahilung presents cultural learning that is not only informative but contextual and applicable.

From a learning theory perspective, Mahilung's design is consistent with a constructivist approach that emphasizes active learning experiences and meaning-making through direct interaction with digital learning environments [21]. HOTS-based mini-games that require situational analysis and problem-solving enable students to construct understanding through a reflective process, rather than simply passively receiving information. This strengthens the argument that game-based learning can be a meaningful medium for knowledge construction.

In addition, the use of gamification elements such as a scoring system, leaderboard, achievement levels, and game time limits is in line with the findings of a meta-analysis by Cadiz et al. [22] and research by Nadeem et al. [23] which showed that digital game-based learning significantly increased student engagement and motivation. Interactive audio-visual features, learning videos, and click-on elements on material images in Mahilung also support the experiential game-based learning approach as explained by Huey Shyh et al. [24], which emphasizes the importance of interaction-based learning experiences to improve media and information literacy.

The relevance of Mahilung as a mobile game-based learning is also strengthened by research by Rahayu et al. [17] which shows that the integration of ethno-edugames in a mobile learning platform can improve the critical thinking and cognitive abilities of elementary school students. Similarly, the findings of Susaniari & Santosa [25] and Jasmaniah et al. [26] confirm that game-based learning with a culturally responsive approach has a positive effect on learning motivation.

In the context of cultural literacy, strengthening local identity through digital media is becoming increasingly relevant in the digital era, as emphasized by Kaunda [1] that literacy in the digital era needs to include cultural dimensions to prevent disruption of local identity. The integration of Dayak content in Mahilung also supports efforts to preserve culture through

modern learning media, in line with research by Ramadhan et al. [27] on increasing cultural literacy through local narratives.

Thus, Mahilung not only represents an innovation in learning media but also presents a culturally based instructional design model that is contextual, adaptive, and potentially replicable in other local cultural contexts. The main contribution of this research lies in the systematic integration of the 4-D model, an offline mobile learning platform, and an ethno-edugames framework in strengthening Dayak cultural literacy at the elementary school level.

Conclusion

This research produces an instructional design for Mahilung Mobile Learning based on the 4-D model (Define, Design, Develop, Disseminate) as an ethno-edugames framework for strengthening Dayak cultural literacy at the elementary school level. Through needs analysis, thematic curriculum reconstruction, offline Android application development with interactive audio-visual materials, HOTS-based mini-games, and a gamification system, this research demonstrates that the integration of Dayak cultural values can be systematically internalized into a contextual and reflective digital learning experience. Dissemination through IPR registration and socialization to elementary school teachers confirms the potential for implementing the product in learning practices. Conceptually, this research contributes to the development of a culture-based instructional design model that is adaptive to the characteristics of the digital generation. For further research, it is recommended to conduct effectiveness testing on a wider scale with experimental designs, develop more immersive interactive features, and replicate the 4-D-based ethno-edugames framework in other local cultural contexts to strengthen cultural literacy sustainably.

Conflict of Interest

The authors declare that there is no conflict of interest.

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