Jurnal Penelitian dan Pengkajian Ilmu Pendidikan: e-Saintika
https://journal-center.litpam.com/index.php/e-Saintika/index

July 2025 Vol. 9, No. 2
e-ISSN: 2615-6881
pp. 345-362

Development of Virtual Reality Games With an Ethnomathematics Approach of Batam Culture for Elementary School Social Arithmetic Materials

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Received: May 2025; Revised: June 2025; Published: July 2025

Abstract

This research develops a virtual reality-based game with an ethnomathematics approach to Batam City culture in the form of Luti Gendang food in learning social arithmetic material in mathematics learning at the elementary school level. This product's development is significant because students are now a digitally native generation and are more interested in learning through technological media than traditional media. Using the ADDIE model as a basis, this research will focus on the development stage, which includes 3 steps, namely (1) initial product design in the form of making storyboards, making learning videos with Adobe Premiere Pro, designing image designs for VR displays, and making learning videos; (2) initial product development focuses on making VR games and conducting validation tests by experts covering the feasibility of material, media, and language to determine the feasibility of the media being developed, and (3) refining the initial product by making revisions and improvements based on the results of the validation test. The development findings demonstrate that: (1) The initial product design incorporates five key menus—VR Simulation, Material, Video, Quiz, and Info; (2) The expert evaluations of the product's feasibility across media, language, and content aspects yielded average scores of 85.2, 80.8, and 83.1, respectively, classifying the product's overall feasibility as excellent; and (3) Subsequent refinements were implemented based on expert validation and user testing feedback, specifically targeting interactivity enhancements, improvements to VR visual elements, and adjustments to in-VR narrations and directional cues.

Keywords: Educational Game; Social Arithmetic; Virtual Reality; Ethnomathematics

How to Cite: Anam, K., Wiradharma, G., Prasetyo, M. A., & Iqbal, M. (2025). Development of Virtual Reality Games with an Ethnomathematics Approach of Batam Culture for Elementary School Social Arithmetic Materials. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *9*(2), 345–362. https://doi.org/10.36312/e-saintika.v9i2.2830

https://doi.org/10.36312/e-saintika.v9i2.2830

INTRODUCTION

Learning media continues to develop with technological advances, moving from print technology, audiovisual technology, and computers to hybrid technology combining print and computer technology. However, there are still many animated media in the technological era that have not been able to bring users as if they enter the animation given because users cannot directly feel the environment in the animation if they only use their sense of sight (Amelia et al., 2021; Serin, 2020). With

such events, it will be more interesting if the animation collaborates with virtual reality (VR) technology.

Currently, virtual reality is one of the latest technological trends used in every field of human needs, including education (Elmqaddem, 2019; Rashid et al., 2021). Virtual reality (VR) uses computer technology to create a simulated environment that can be explored from a 360-degree angle, and the natural environment in the real world will be copied into the virtual environment. The reason for choosing virtual reality is its very high ability to visualize objects close to their original form. VR will place the user in a virtual environment generated from a computer-simulated environment to provide an experience of interacting with virtual objects. The elements of VR consist of the virtual world, immersion, sensory feedback (vision, hearing, touch), and interactivity (Çoban & Göksu, 2022; Mariscal et al., 2020; Serin, 2020). VR makes it easier for students to remember, understand, and concentrate faster (Çoban & Göksu, 2022; Kamińska et al., 2019; Molina-Carmona et al., 2018). In addition, VR has the advantage of attracting students to new worlds and can increase the effectiveness of the learning process in the classroom (Sattar et al., 2019; Vergara et al., 2019). However, so far, the activities carried out by students are only limited to remembering and reading books and listening to subject matter from the teacher. Passive activities become boring for students.

Much progress has recently been made in using VR in educational environments. Most of the research in this area focuses on finding ways to make learning materials more engaging and interactive for students. Many studies have shown that VR can increase student motivation to learn by providing an engaging environment and enabling a more dynamic and interactive learning experience. VR in the learning process is appropriate because it makes learning more meaningful (Raja & Priya, 2021; Shin, 2017). Given that students now belong to the digital native generation, they are more interested in learning using technological media than just using traditional media. VR can improve students' learning outcomes and skills because students find it easier to learn the material given, and the learning process in the classroom is not dull (Molina-Carmona et al., 2018; Paszkiewicz et al., 2021).

VR has also been shown to improve conceptual understanding, particularly in subjects that require strong visualization of space, such as mathematics and science. According to Zulmaulida et al. (2021), VR is a system that simulates the sensation of being in three-dimensional (3D) space, like the real world. VR media allows users, especially students, to engage in unique experiences by taking them to different environments. The education curriculum demands the integration of culture into the education process to produce a generation capable of preserving and developing the culture that is the foundation of the nation's character. Advances in educational technology are also a supporting factor. Instilling cultural values can be done through the school environment, using an ethnomathematics approach to learning. Cultural practices facilitate the integration of mathematical concepts and the recognition that all individuals develop unique methods of performing mathematical activities, known as ethnomathematics.

Ethnomathematics examines mathematics and its practices in a cultural context. Its application in education aims to make mathematics learning more culturally relevant, which can help students understand and appreciate mathematics as part of their daily lives and cultural heritage. Using ethnomathematics has improved

students' understanding of mathematical concepts by connecting learning materials to cultural contexts and familiar practices. Ricardo's research (2016) also revealed that ethnomathematics allows students to develop mathematical concepts by utilizing their knowledge because it is based on the student's environment. The study findings of Ayu et al. (2016) show that the learning outcomes of classes that use ethnomathematics learning differ from those that do not. This is evidenced by the T-test results, which show that acquiring ethnomathematics skills impacts students' mathematical understanding ability. The ethnomathematics approach in the traditional children's game "ingkek-ingkek" succeeds in integrating mathematics material, especially the material of recognizing numbers, flat shapes, and opportunities, into the world of everyday life that is fun for children, according to socio-cultural life in the traditional area of Koto Tengah, Sungai Penuh City, Jambi Province, according to Rusliah's ethnomathematics research.

However, although various studies have examined the use of Augmented Reality (AR) and Virtual Reality (VR) technologies in mathematics learning at the elementary school level, most of the focus remains limited to geometry topics or spatial literacy skills. The study by Gustina and Mariana (2025) showed that AR-based learning media can improve students' spatial abilities in solid geometry. Similarly, Pramulia et al. (2025) utilized AR-based comics with an ethnomathematics approach to enhance students' literacy and numeracy.

Nevertheless, research that specifically develops VR-based mathematics learning media with an ethnomathematics approach for social arithmetic topics remains very limited. Although Anam et al. (2024) designed a VR-based learning game with an ethnomathematics approach for social arithmetic, the study was more exploratory in design and did not evaluate its effectiveness in real classroom settings. Meanwhile, Rahmawati et al. (2022) reported on the effectiveness of VR and ethnomathematics-based mathematics learning media, but their study did not yet incorporate specific local cultural contexts as a means of contextual learning.

Based on these conditions, there is still significant room for research that contextually integrates VR and the ethnomathematics approach, particularly in teaching social arithmetic embedded with local cultural values. The development of VR-based learning media with an ethnomathematics approach through traditional food trading activities of Luti Gendang from the Riau Archipelago represents an innovative practice that has not been widely explored, yet holds potential to enhance students' understanding of mathematical concepts while instilling cultural values and financial literacy from an early age.

The development of mathematics learning media using Virtual Reality (VR) technology and an ethnomathematics approach is based on three main, interconnected pillars: technology-based interactive visualization, meaningful cultural context, and students' cognitive processes in understanding mathematical concepts. VR technology enables the creation of immersive learning environments, where students can directly experience and interact with three-dimensional visual representations of abstract concepts. In the context of mathematics education, VR's ability to simulate real-life situations supports the development of experiential learning and strengthens students' conceptual understanding (Çoban & Göksu, 2022; Molina-Carmona et al., 2018).

Meanwhile, the ethnomathematics approach places mathematics within a local cultural context, allowing students to see a direct connection between their lived experiences and the mathematical concepts being taught. This can enhance both cognitive and affective engagement, as the learning materials become more relevant to their reality (Ricardo, 2016; Ayu et al., 2016). Through contextual activities such as the traditional food trading of Luti Gendang, students not only grasp the numerical aspects of social arithmetic but also absorb the cultural and economic values of the local community.

The integration of VR and ethnomathematics is expected to produce contextual, interactive, and immersive learning media that can improve the effectiveness of social arithmetic instruction. Through this approach, students gain a more holistic learning experience that includes conceptual understanding, critical thinking skills, and reinforcement of cultural and financial literacy. Theoretically, the synergy between these two approaches is believed to enhance learning outcomes by fostering active student engagement in the construction of meaning from the material being learned.

Mastery of mathematical knowledge is essential in everyday life, and one of the applications is learning social arithmetic. However, interviews with instructors show that students still experience problems in solving story problems. This is reinforced by research by Nuraeni et al. (2020), which revealed that social arithmetic problems continue to be a challenge for most students. Causal factors undoubtedly support the problem. Internal factors are caused by students' challenges when solving social arithmetic story problems. These challenges include (1) language, (2) prerequisites, and (3) calculations and conclusions applied (Dila & Zanthy, 2020). Instructors' selection and utilization of learning media is an essential factor contributing to student learning outcomes (Udil & Sangur, 2020).

Social arithmetic is an essential topic in mathematics education that focuses on basic numerical operations relevant to everyday activities, often attracting the attention of teachers and students when taught through various learning media (Friantini et al., 2020). The study of social arithmetic also enriches students' experience in financial literacy, investigating the fundamental properties of numbers and mathematical operations such as addition, subtraction, multiplication, and division, which are essential for practical applications in everyday life (Harahap, 2010). This study integrates an ethnomathematics approach, focusing on the cultural activities of communities in Riau Islands Province, specifically through the cultural product Luti Gendang, a type of bread filled with shredded fish or chicken. The origin of Luti Gendang from the Anambas Islands Regency highlights the local utilization of ingredients, such as wheat flour, milk, eggs, butter, sugar, and shredded tuna with traditional Malay spices, resulting in a characteristic oblong shape and an alluring savory taste.

On the other hand, using games as educational tools represents an innovation in modern education, with various models and types of games used to enrich learning media to improve student motivation, understanding, and learning outcomes (Hermawan et al., 2017). Pramuditya et al. (2018) support this approach, which shows that educational games offer innovative solutions as learning media that are interesting and fun and are expected to improve students' mathematical understanding skills.

Given the growing demand for culturally responsive and technologically immersive learning, the development of mathematics learning media based on Virtual Reality (VR) with an ethnomathematics approach emerges as both a timely and novel contribution to elementary education. Unlike most existing studies that concentrate on VR applications in geometry or spatial literacy, or that apply ethnomathematics in abstract or non-localized contexts, this study uniquely integrates VR with the ethnomathematical context of *Luti Gendang*, a traditional culinary practice from the Riau Archipelago, to teach social arithmetic. This localized and narrative-based integration serves as the novelty of this research. It departs from prior works by embedding cultural economic activities directly into an immersive VR environment, thereby enhancing conceptual understanding while simultaneously fostering cultural appreciation and financial literacy (Christopoulos et al., 2024). The innovative combination of experiential VR simulation, context-based numeracy, and ethnocultural identity offers a holistic model for mathematics instruction—one that has not been comprehensively explored in prior studies, especially within the scope of Indonesian elementary education.

This study aims to develop an educational game-based VR learning media using an ethnomathematics approach that highlights a local cultural context—specifically, the traditional food trading activity of Luti Gendang from the Riau Archipelago. This media is expected not only to enhance students' understanding of social arithmetic concepts but also to instill cultural and financial literacy from an early age. Through this innovative approach, the study is expected to contribute to the development of contextual learning resources that are adaptive to the demands of the times and the characteristics of digital-native learners. Furthermore, the findings of this study have the potential to serve as a reference for the development of similar media in various other cultural contexts across Indonesia.

METHOD

Research Design

This study employs the Research and Development (R&D) method as the core methodology, particularly adapted for the development of a Virtual Reality (VR) educational game integrating ethnomathematics. This approach facilitates the design, iterative development, and evaluation of learning tools. As stated by Sugiyono (2017), R&D aims to create new products and assess their feasibility and effectiveness. Ethnomathematics serves as a contextual foundation to embed cultural relevance into mathematical learning. Moreover, the self-paced instruction model provides learners the flexibility to manage their learning time independently based on their individual capacities.

Instructional Design Model

To guide the systematic development process, the study adopts the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation), which is widely recognized in instructional design. According to Romiszowski (in Ma'ruf, 2021), ADDIE supports the structured creation of learning materials, including VR-based applications, due to its theoretical grounding and adaptability to various technological platforms. For VR-based education, integrating instructional design

with game engines like Unity enhances interactivity and immersion (Bacca et al., 2014; Radianti et al., 2020).

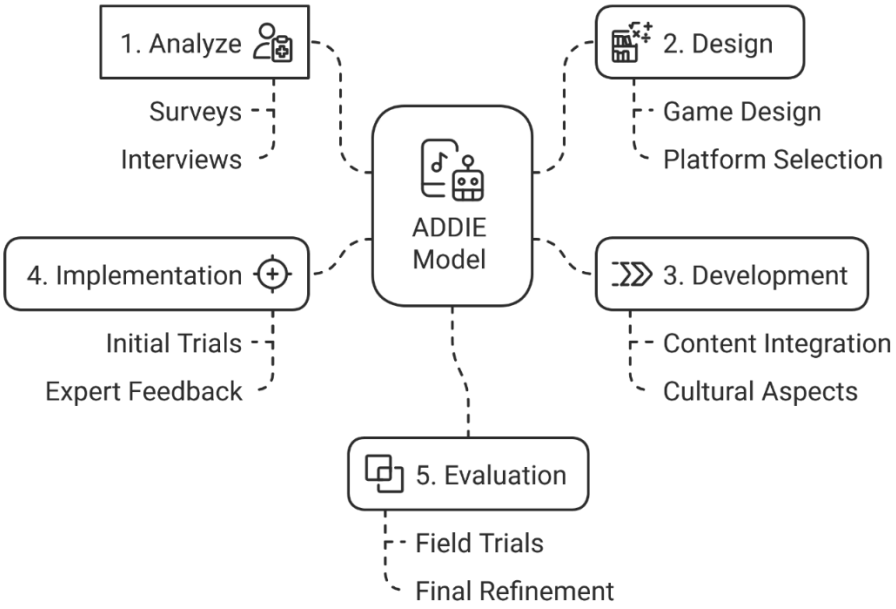

Figure 1. Customized ADDIE Model Diagram for Ethnomathematics-VR Game Development

Phase Descriptions

Analysis. This stage involved identifying learner needs and ethnomathematical aspects relevant to social arithmetic. Data were gathered through surveys and interviews with mathematics teachers and students across several schools. These instruments aimed to capture cultural contexts, curriculum relevance, and learner preferences.

Design. Based on the analysis, VR learning content and ethnomathematical elements were planned. Storyboards, learning objectives, and flow structures were created. The Unity 3D platform was selected due to its flexibility in educational game development and compatibility with VR hardware (Cheng & Tsai, 2019). Instructional design principles such as Mayer's Multimedia Learning Theory and Cognitive Load Theory were considered in interface planning.

Development. This stage entailed creating the VR game's alpha version. Ethnomathematical problems were embedded in culturally relevant scenarios using virtual assets. The development included scripting, modeling, and integrating user interactions using Unity.

Implementation. The prototype was piloted with a limited number of users. Expert feedback was gathered to improve content accuracy, pedagogical value, and user experience. The revision followed iterative cycles of testing and refinement.

Evaluation. A main field test was conducted to evaluate the application's usability, content relevance, and effectiveness in supporting learning. The feedback guided final modifications before deployment.

Study Timeline

The five stages are divided into design, development, and evaluation. The duration of this study is two years. In 2024, the first year is dedicated to the design and development phase. The evaluation of the VR game will be conducted in the

following year. The VR game's development phase includes the primary focus of the research process.

Expert Validation

Three expert validators were involved in evaluating the VR game prototype. Their selection was based on specific criteria:

1. Media Expert: Minimum 5 years of experience in educational technology and proficiency in VR/game-based learning development.
2. Language Expert: Holding at least a Master's degree in language education with specialization in instructional material development.
3. Mathematics Education Expert: Background in mathematics curriculum and assessment with experience in contextual learning or ethnomathematics research.

These experts were selected through purposive sampling, considering both academic qualifications and professional portfolios in relevant fields.

Data Collection and Analysis

Data was collected using a customized questionnaire to assess aspects of ethnomathematics in learning. The data was then subjected to quantitative descriptive analysis to assess the feasibility and quality of the developed application and the effectiveness of using ethnomathematics as a learning approach. This analysis aims to quantify the questionnaire results based on predetermined score weights and detail the attributes of the data obtained. The analysis findings become the basis for the revision and development of the application, with the assessment using a Likert scale from 1 to 4 to interpret the data. The developed product is suitable if the interpretation level is ≥ 60%, as determined by the Likert scale score calculation (Riduwan, 2012).

Table 1. Likert Scale Rating

Answer	Rate
Strongly Agree	4
Agree	3
Disagree	2
Strongly Disagree	1

Ethical Statement

This study received approval from the institutional ethics committee and complied with the Declaration of Helsinki and relevant national guidelines. Informed consent was obtained from all participants, who were assured of anonymity and the exclusive use of their data for research purposes. Personal data were anonymized during collection and analysis to ensure confidentiality. The study posed no physical, psychological, or social risk, and cultural sensitivities were respected throughout the integration of ethnomathematical content. Expert validators were selected purposively based on qualifications and experience, with no conflicts of interest. Their role focused solely on evaluating pedagogical, linguistic, and technological aspects of the VR game.

RESULTS AND DISCUSSION

The findings of this study are a VR-based elementary school social arithmetic learning game application named " SIVIRA: Social Arithmetic Virtual Reality Application. "The learning game that has been designed must use VR devices. This

media contains VR simulations, materials, learning videos, exams, and media information aligned with the students' and teachers' needs analysis findings. SIVIRA was developed to facilitate independent learning for students and the public.

The SIVIRA application development process adheres to the ADDIE development model, which consists of five main phases: analysis, design, development, implementation, and evaluation. The process was divided into three main phases: planning (analysis), development (designing and developing), and evaluation (implementation and evaluation). The focus of this study is the SIVIRA product development phase.

The development stage includes three stages: (1) initial product design in the form of making storyboards and learning videos using Adobe Premiere Pro; (2) initial product development in the form of validation tests by experts who assess the feasibility of materials, media, and language to determine the feasibility of the media developed; and (3) initial product improvement. The initial product design stage includes making learning videos and designing images for VR displays. The initial product development stage aims to develop learning videos and VR displays. This stage involved media, materials, and language specialists to identify the shortcomings of the developed videos and VR. Subsequent revisions were then implemented. The initial product refinement stage was further conducted by incorporating expert feedback to improve the social arithmetic learning video and VR in the office administration course. After developing this VR media, the expected result is that this media will be declared valid and suitable for educational purposes.

Initial Product Design

The first year of this research is dedicated to creating an instructional video that will serve as the content for social numeracy VR. The instructional video that has been produced can be useful and can help students in the study of office administration. Putra's research findings (2013) reinforce this point of view, showing that innovatively designed teaching materials can facilitate the learning process and benefit students.

In the development of social arithmetic material, there are several sub-materials, namely (1) Introduction to Selling Price and Purchase Price, (2) Profit and Loss, and (3) Discount. In VR media, there will be PowerPoint material, learning videos, quizzes, and VR simulations in organizing space. The VR simulation developed also uses the ethnomathematics approach of Makassar culture, namely Jalangkote, where students play a role in the social arithmetic of buying and selling Jalangkote. The SIVIRA development process has adjusted the needs analysis stage that was carried out previously. The learning videos on display also include explanations of materials, concepts, and applications of various concepts according to student needs. After making the storyboard and video, experts evaluated the video and VR products to ensure their suitability as learning media for social arithmetic material.

The prototype development process was based on the VR development carried out in various previous studies. Specifically, the concept of a virtual reality operating system (VR-OS) with a head-mounted display (HMD) and game engine-based hand gesture recognition technology (Unity3D) was used to create a more comprehensive and spacious work environment for users by implementing a 360° workspace (Kim et al., 2017). Duane et al. (2020) used virtual reality as a medium for interactive information questions. Nisiotis et al. (2020) researched using VR prototypes to

envision a system that connects visitors with events and objects separated in space, time, or both, thus providing a social meeting point.

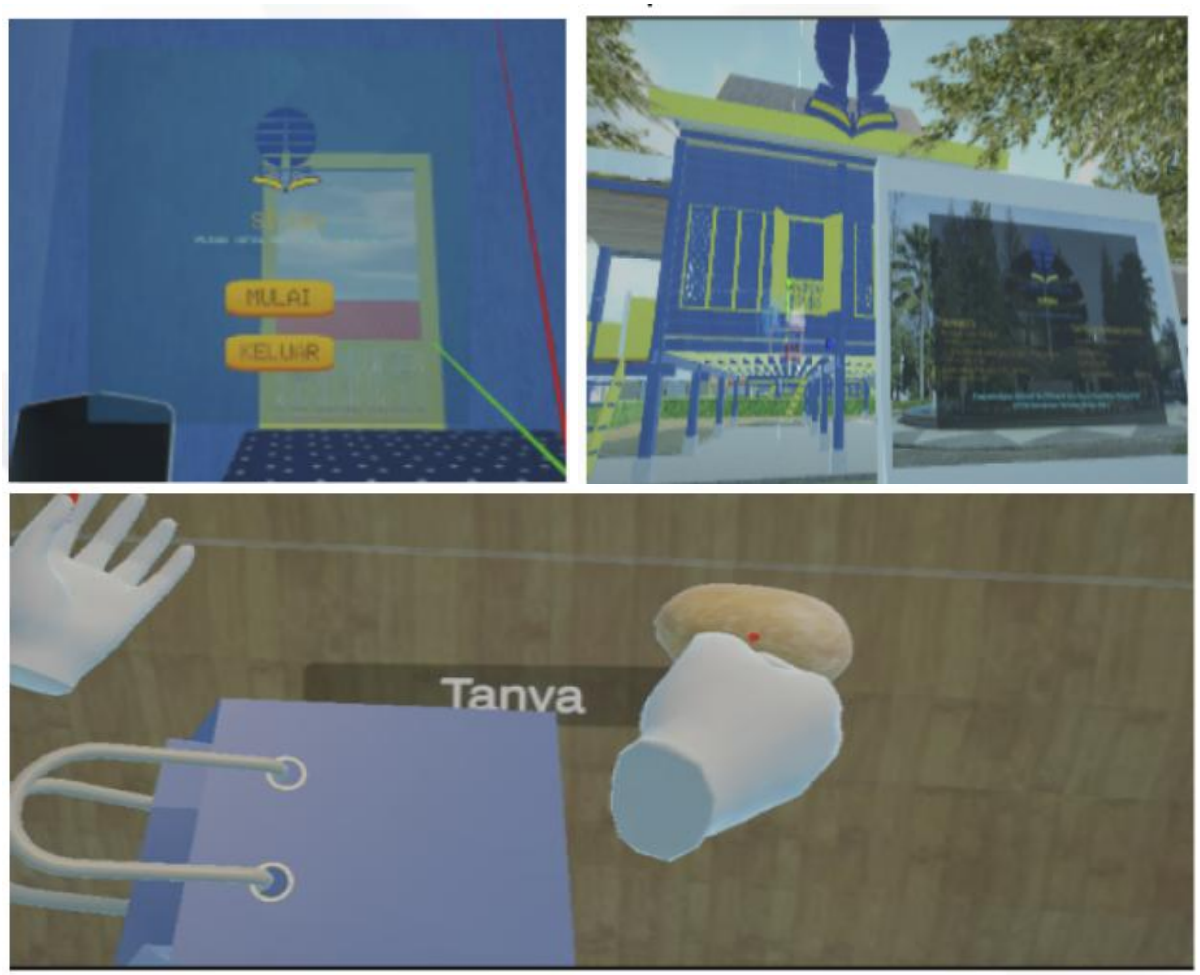

Figure 2. Display of SIVIRA: Home Page, VR environment, and interaction with *Luti Gendang*

The SIVIRA interface comprises six main sub-menus: VR Simulation, Material, Video, Quiz, and Info, each designed to support elementary students in learning social arithmetic through an immersive VR experience (as illustrated in Figure 2). The VR Simulation sub-menu offers an interactive educational game simulating the buying and selling of *Jalangkote* in a traditional market, allowing students to explore contextual pricing through social arithmetic. This component is deliberately designed to be engaging to foster motivation and interest among young learners.

The Material section presents PowerPoint-based learning materials directly in the VR environment. These materials—adapted from various books and educational websites—were tailored to align with the curriculum needs of elementary-level social arithmetic. The Video sub-menu provides audiovisual content derived from the same learning materials, aiming to enhance conceptual understanding through contextualized explanations. Meanwhile, the Quiz section includes multiple-choice assessments to evaluate students' comprehension, offering immediate feedback on scores and correct answers. These quizzes are compiled and adapted from various math problem sources.

Finally, the Info menu provides detailed information about the SIVIRA application itself, including technical specifications, developer details, and references used in the application's development. Each sub-menu is integrally connected to support a cohesive and engaging learning journey.

Product Development

After designing the initial product, the research continued at the SIVIRA development stage. The SIVIRA development process was carried out by testing the feasibility of virtual reality applications that have been developed practically. This was applied to improve the VR application. The feasibility test used a questionnaire to collect responses from material, language, and media experts. The following describes the mobile learning feasibility test involving material, language, and media experts.

The feasibility test was conducted by experts to gather feedback regarding the VR application currently being developed. Experts in their respective fields, including material, language, and media experts, conducted this check. Initially, the experts evaluated and observed the VR that had been developed. Next, the experts were asked to complete a questionnaire. The assessment results were based on the feasibility of the VR material, language, and media.

Media Feasibility Test Results

There are three components in the media validation test assessment: (1) visual and audio display of virtual reality, (2) use of virtual reality media, and (3) software engineering and implementation. Table 2 displays the results of the media experts' evaluation of the feasibility of media in VR.

Table 2. Results of Feasibility Test by Media Experts

No.	Aspects	Items Number	Average Feasibility (%)	Criteria
1	Visual and audio display of virtual reality	1-10	83.3	Very good
2	Use of virtual reality media	11-15	87.5	Very good
3	Implementation and software engineering	16-18	84.7	Very good
Average Overall Score			**85.2**	**Very good**

The feasibility test conducted by media experts on the SIVIRA virtual reality application assessed three key aspects: visual and audio display, media utilization, and software implementation. First, the visual and audio display of the VR media was evaluated using six indicators, including layout accuracy, design suitability, image clarity, text appropriateness, audio relevance, and video quality. These elements collectively received an average feasibility score of 83.3%, indicating that the visual and auditory components of SIVIRA met the "Very Good" criteria. Second, the use of VR media was examined through five items that measured the effectiveness of VR components in facilitating mobile learning. This aspect yielded an average feasibility rating of 87.5%, again categorized as "Very Good." Lastly, the implementation and software engineering were evaluated based on media quality and ease of use, both of which demonstrated strong feasibility with results aligning with the "Very Good"

category. These findings collectively affirm that SIVIRA's design, usability, and technical implementation are well-developed and suitable for use in educational settings.

The aggregate average of the SIVIRA media assessment results was 85.2%, with the interpretation of "Very Good" obtained by combining the percentage results of the three aspects. In addition, the media experts provided input and recommendations related to SIVIRA, which were compiled as follows:

> "*It is very important to verify that the Android operating system used in the development of the app or educational material is compatible with the required version and specifications to guarantee the correct operation of the app. Consistency between the proportions of text and images should also be considered to ensure a harmonious visual balance. It is recommended to use a typeface that is standard for scientific writing, which facilitates reading. The colors of the text, images, and background should be carefully chosen to be appropriate and easy to read, thus facilitating understanding of the material. In addition, adding a caption at the bottom of each button will help users understand its function without the need to frequently return to the hint menu, making navigation more intuitive and efficient.*"

The VR media was refined to improve its quality based on the recommendations and feedback from the media experts. Researchers refined the components in the commented sections according to the recommendations and feedback from the media experts.

Language Feasibility Test Results

The language validation test assessment includes three components: sentence effectiveness, communicative sentences, and easy-to-understand language. The assessment instrument was developed according to the media language feasibility standards as required. The results of the language feasibility assessment are presented in Table 3.

Table 3. Results of Feasibility Test by Linguists

No.	Aspects	Items Number	Average Feasibility (%)	Criteria
1	Sentences effectiveness on virtual reality	1-5	80.4	Very good
2	Communicative sentences on virtual reality	6-10	82.8	Very good
3	Language on virtual reality is easy to understand	11-15	79.2	Good
Average Overall Score			**80.8**	**Very good**

The linguistic evaluation of the SIVIRA application, conducted by expert linguists, focused on three key aspects: sentence effectiveness, communicative quality, and language clarity. In terms of sentence effectiveness, the application achieved an average eligibility score of 80.4%, which places it within the "Very Good" category, indicating that the sentence structures used in the VR environment are generally well-constructed and appropriate. The communicative quality of the sentences—assessed

through their clarity and ability to convey meaning effectively—received an average feasibility score of 82.8%, also falling into the "Very Good" classification. Meanwhile, the clarity and comprehensibility of the language used in the VR media scored an average of 79.2%, which, while slightly lower, still falls under the "Good" category. These results suggest that the language used in SIVIRA is largely effective and communicative, though there may be minor areas for improvement in enhancing the ease of understanding for all users.

The language feasibility of this virtual reality was rated "Excellent" overall, with an aggregate average of 80.8% based on the percentage results of the three aspects. The linguist provided the following suggestions and comments in addition to the assessment.

> "*It is important to choose the right words and ensure that the language used is familiar to the user to make the material easier to understand. Using language that is engaging and can spark curiosity will make user interaction more interesting. It is also important to avoid overloading the media with too much text, which can quickly tire or bore users. Only the most important and relevant information should be included to maintain engagement and learning effectiveness.*"

Based on the linguists' statements and recommendations, the VR media was refined to improve its quality. Researchers refined the components in the commented sections according to the linguists' recommendations and feedback

Material Feasibility Test

The material validation test assessment includes three components: content feasibility, presentation feasibility, and utilization of ethnomathematics content in VR media. The results of the material feasibility assessment are presented in Table 4.

Table 4. Feasibility Test Results by Material Experts

No.	Aspects	Items Number	Average Feasibility (%)	Criteria
1	Feasibility of content on virtual reality media	1-10	83.3	Very good
2	Feasibility of presentation on virtual reality media	11-13	80.2	Very good
3	Use of ethnomathematics content	14-16	85.7	Very good
Average Overall Score			**83.1**	**Very good**

The material feasibility assessment of the SIVIRA virtual reality application, as conducted by subject matter experts, encompassed three main dimensions: content accuracy, presentation quality, and the integration of ethnomathematics. Regarding the feasibility of content, which was measured through indicators such as content accuracy and alignment with basic competencies, the average eligibility score was 83.3%, indicating that the material meets the "Very Good" standard. The feasibility of presentation, assessed based on material presentation techniques and supporting elements, received an average score of 80.2%, placing it within the "Good" category—suggesting the delivery is generally effective but may benefit from minor enhancements in engagement or clarity. Notably, the application's incorporation of

ethnomathematics content, which was evaluated through a single indicator and three related questions, achieved a high score of 85.7%, signifying a "Very Good" level of integration. This indicates that SIVIRA not only aligns well with educational competencies but also effectively contextualizes learning through culturally relevant mathematical practices.

The average result of the SIVIRA media material assessment was 83.1%, with an interpretation of "Very Good" based on the percentage results of the three aspects. It includes the following suggestions and comments from the material expert assessment:

> *"The VR media developed is adequate and suitable for use. However, they suggest that the virtual reality (VR) aspect be improved to make the visualization look more realistic and facilitate understanding. In addition, it is recommended to include examples that are relevant to real-world scenarios to increase the contextualization of learning about building space. In addition, the material can be enriched with additional explanations of surface area components to provide a more comprehensive understanding."*

The VR application was refined to make it more effective based on the suggestions and comments of the material experts. The researcher improved the components in the commented sections according to the recommendations and feedback of the material experts.

Several studies have been conducted, and the results of SIVIRA development research align with these findings. This VR-based learning media is very effective and meets the demands of learning activities that focus on the concepts of the sun and plants. This virtual reality-based learning media may improve student learning outcomes (Tarmizi et al., 2020). The advantages of learning media developed based on VR include being able to be observed directly in VR form so that students do not need to imagine geometry shape nd can observe it directly in teaching and learning activities. The VR-based learning media allows students to observe shapes directly in teaching and learning activities. This is because the media is presented in VR form and can be observed by students. This VR-based learning media is visually appealing and utilizes the latest technology. Based on the validation test results of experts in learning media and teaching materials, this VR-based learning media is very valid and suitable for learning activities (Musril et al., 2020).

According to experts, the benefit of learning with video and VR products is that they offer new knowledge insights to students in terms of concepts and applications of online learning media. The ethnomathematics approach can also contextualize learning and familiarize students with Indonesian culture. The learning video is more engaging and equipped with illustrations, visuals, and music, which enhances the learning experience. In addition, this media can be accessed anytime and from anywhere, is easy to use, and can be used repeatedly. Videos and simulations can only be accessed through the VR application provided, so an adequate internet network and VR device are required in addition to the benefits of learning videos.

Product Refinement

Refining the VR product developed in this research includes a critical step in ensuring the SIVIRA application meets technical and educational standards and resonates with students' learning experiences. Based on the results of the validation test by experts and feedback from users in the field trial, several important aspects

that require improvement and adjustment have been identified. First, in terms of interactivity, it was found that users preferred an intuitive and responsive interface. Therefore, the development team has improved the responsiveness of gesture control in VR, allowing students to interact with the learning materials more naturally. This improvement is expected to increase student engagement and make it easier to master the social arithmetic concepts being taught. Secondly, the visual aspect of the VR simulation is improved to make the objects and characters in the application appear more realistic and attractive. This was done by enriching the texture and lighting details in the VR environment, which improves the visual aesthetics and helps facilitate concept understanding through better visualization. Third, based on feedback on how students process information, the development team has modified the narration and directions in VR to ensure the instructions are more precise and accessible. Adjustments to the language used in the instructions have also been made to ensure they are appropriate for elementary school students' level of understanding, by integrating more definitions and interactive explanations.

Through this product improvement process, the SIVIRA application is now more effective in delivering subject matter, attractive, and accessible for students to use. This research demonstrates the importance of design iteration and evaluation in developing technology-based educational tools. The constructive feedback given on SIVIRA and the implementation of continuous improvement is critical to achieving optimal learning outcomes.

CONCLUSION

This study developed and validated an educational game called *SIVIRA*, which integrates Virtual Reality (VR) and an ethnomathematics approach for social arithmetic learning at the elementary school level. By embedding culturally relevant contexts such as traditional market transactions involving *Luti Gendang* into mathematical concepts like cost, selling price, and profit, *SIVIRA* provides a contextualized and immersive learning experience that supports both cognitive engagement and cultural relevance. The integration of VR and ethnomathematics was shown to enhance the feasibility of the learning media, as indicated by expert assessments in three areas: media (85.2%), language (80.8%), and content (83.1%), all categorized as "Very Good." These findings indicate that the product is technically feasible and pedagogically sound for classroom implementation, particularly for introducing contextual numeracy grounded in students' local culture. Rather than making generalized claims about replication or broad-scale impact, this study demonstrates the realistic potential of localized VR-ethnomathematics integration to enrich social arithmetic instruction and promote financial literacy in culturally meaningful ways. The instructional model and media developed in this study can serve as a practical reference for educators and developers seeking to adapt similar approaches in other regions with appropriate cultural adjustments. Future research may further investigate its effectiveness through classroom implementation involving students as end users.

RECOMMENDATIONS

To amplify the impact and adoption of the SIVIRA application, several strategic recommendations are proposed. First, scalability and regional adaptation are

essential; the SIVIRA model should be expanded to reflect diverse cultural and linguistic contexts across Indonesia—such as Bataknese, Dayaknese, or Balinese traditions—by collaborating with local educators and cultural experts to identify relevant ethnomathematical elements. Second, ensuring inclusivity and accessibility is critical. Future iterations of SIVIRA should integrate features that support students with disabilities, including captioned narration, adjustable text sizes, and simplified controls for learners with motor impairments. These enhancements would align the application with Universal Design for Learning (UDL) principles, promoting broader educational equity. Third, SIVIRA's design is already in harmony with the Merdeka Belajar curriculum, which encourages independent, differentiated, and context-rich learning. By enabling students to explore mathematics through culturally familiar contexts, SIVIRA contributes to the development of Profil Pelajar Pancasila, fostering cultural awareness, collaborative learning, and critical thinking. Lastly, further research and comparative studies are recommended to assess SIVIRA's effectiveness in relation to conventional or alternative digital learning tools. Engaging both students and teachers in usability testing will provide valuable insights and enhance ecological validity. By pursuing these directions, the continued development of SIVIRA holds the potential to foster a culturally responsive and technologically enriched approach to mathematics education, both within Indonesia and potentially in other multicultural settings.

Author Contributions

The authors have sufficiently contributed to the study. All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by LPPM-UT in 2024.

Acknowledgement

The researcher would like to thank LPPM-UT for funding this research activity in 2024 and the speakers who have provided input on the development of VR-based social arithmetic learning games.

Conflict of interests

The authors declare that there are no conflicts of interest in this study.

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