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Bridging Culture and Technology: Integrating Minangkabau Ethnomathematics into Virtual Reality for Geometry Learning

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Abstract: This research is based on the fact that younger generations have difficulty understanding mathematics and are also less culturally aware. Observing this phenomenon, it is necessary to develop a culture-based (ethnomathematics) learning media. The purpose of this study is to develop an ethnomathematics-based mathematics learning media by exploring the Minangkabau *Rumah Gadang* (traditional house) through virtual reality technology. The research method used in this study was research and development (R&D), which followed the ADDIE model, which consists of five phases: analyze, design, develop, implement, and evaluate. The media was developed using the Artsteps application. The media developed was validated by experts before being tested on students as research subjects. Data were collected from two material-expert lecturers and one media-expert lecturer, as well as from one class of 44 students, serving as the product trial sample. The instruments used in this study were the material expert validation sheet, the media expert validation sheet, the student response questionnaire, and the mathematics learning achievement test. The results of this study showed that the material expert gave a score of 98%, the media expert 97%, and the practitioners (student responses) 98%, with an average score of 97.7%, which falls into the "excellent" category. Meanwhile, the mathematics learning achievement test showed that 84.1% of the students met the passing criteria in this course, while 15.9% failed. Based on the research results and discussion, it can be concluded that the Minangkabau culture-based ethnomathematics learning media developed through the ADDIE model meets the criteria for validity and practicality for implementation with Elementary School Teacher Education students.

Keywords: ethnomathematics, virtual reality, mathematics, learning_media

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INTRODUCTION

Education, of course, plays a crucial role in introducing students to cultural diversity through school-based learning activities, including mathematics. However, the results of observations conducted by the researcher, from elementary school to university level, show that most students dislike mathematics because Mathematics learning is often considered abstract and challenging to understand, which decreases their interest and comprehension. This is supported by research conducted by Marhami et al. (2024), which found that, overall, Indonesian secondary school students still experienced difficulties in using mathematical operations, understanding problems, applying strategies, and interpreting the results of solving PISA-type questions in the areas of space and shape, change and relationships, quantity, uncertainty, and data content. These findings indicate that the material considered most difficult by Indonesian students is Space and Shape geometry. Putri et al. (2025) also found that students often struggled to understand abstract, difficult-to-relate-to mathematical concepts. One approach to addressing this issue is ethnomathematics, a learning approach that connects mathematical concepts with local culture (Supriyadi et al., 2024). This is supported by research conducted by Rahmawati et al. (2024) and Munir (2019), which states that ethnomathematics-based learning not only improves students' mathematical skills but also enhances their cultural understanding. Meanwhile, the research of Prahmana & D'Ambrosio (2020)shows that implementing ethnomathematics in schools requires a specific formula to make it easier for teachers to apply.

Ethnomathematics is a field of study that examines the relationship between mathematics and culture, exploring how different communities develop, use, and transmit mathematical concepts within their cultural contexts (Kariadinata et al., 2023). This approach enriches mathematics education by making it more relevant and inclusive, connecting mathematical abstractions with real-life experiences. Alongside technological advancements, there is growing potential to integrate immersive technologies, such as Virtual Reality and Augmented Reality, into ethnomathematics to enhance learning experiences and conceptual understanding.

Immersive technology offers interactive, engaging learning environments that allow users to interact with digital visualizations and simulations (Bertrand et al., 2024). Augmented Reality can project virtual components into the real world in real time, enabling interaction with 3D objects as if they were real (Kariadinata et al., 2023). Meanwhile, Virtual Reality fully immerses learners in a virtual environment, replacing the physical world with simulations rich in sensory stimuli (Bertrand et al., 2024). The integration of immersive technology into mathematics education has been shown to improve student engagement and understanding (Yazdi, 2025).

The use of VR and AR in ethnomathematics has significant potential to enrich students' understanding and experience of mathematical concepts rooted in culture. VR and AR tools can support the abstraction of concepts in tangible ways through student interaction, idea exchange, teamwork, and collaboration (Bertrand et al., 2024). Research shows that immersive experiences can facilitate understanding of geometry (Nathal et al., 2018), enable mathematical exploration through physical movement in digital environments, and support collaboration in VR settings (Huang et al., 2023). Furthermore, adapting AR and VR activities to students' cultural backgrounds and interests can provide opportunities to explore diverse cultures and encourage self-discovery (Bertrand et al., 2024).

Other works also highlight the use of AR to illustrate geometric concepts related to ethnomathematical values, such as traditional houses (Saphira, 2022). In addition, these technologies hold potential for the discovery, reconstruction, experience, and learning of cultural heritage (Upasani et al., 2023), which aligns with the goals of ethnomathematics. Nevertheless, implementing these immersive technologies is not without challenges, including technical issues, hardware limitations, and navigation constraints (Bertrand et al., 2024).

Various studies on the development of ethnomathematics learning media have previously been conducted, including those by Kartono et al. (2020). These studies utilized conventional and non-immersive digital learning media, including student worksheets (LKPD), printed modules, two-dimensional visual media, and applications based on Augmented Reality and interactive multimedia. These media were effective in integrating cultural contexts into mathematics learning, particularly for introducing geometric concepts through visual representations of local culture.

However, these studies have not yet utilized immersive Virtual Reality technology, which allows students to directly interact within a three-dimensional virtual environment, spatially explore cultural objects, and experience geometry learning through more in-depth visual and kinesthetic experiences. Therefore, this study seeks to fill this gap by developing Virtual Reality-based learning media for plane geometry integrated with Minangkabau culture, and by testing its feasibility through expert validation and student responses.

The Minangkabau culture has a wealth of geometric forms that can be integrated into the learning of plane geometry, such as the triangular shape of the *Rumah Gadang* roof and its symmetrical carved motifs. Along with technological advancements, Virtual Reality (VR)-based learning media have become an innovative alternative, offering immersive, interactive learning experiences. Many researchers have conducted research and development on ethnomathematics media in mathematics learning, as carried out by Danoebroto (2024), Utami (2019), and Nur et al. (2020). However, these studies have not yet utilized Virtual Reality. This study develops a VR learning medium for plane geometry grounded in Minangkabau culture and tests its feasibility through expert validation and student responses.

Culturally based mathematics learning (ethnomathematics) can help students understand subject matter by drawing on prior knowledge from their surroundings. Introducing local culture to students is expected to help preserve regional cultural heritage passed down from ancestors (Purwanto & Junaedi, 2025). Ethnomathematics refers to the mathematical knowledge of a sociocultural group, used to reason and draw conclusions. According to D'Ambrosio, ethnomathematics is the field that studies how specific cultural groups understand, communicate, and use mathematics in their daily lives (Orey & Rosa, 2022). Ethnomathematics is also part of research on mathematical knowledge within a culture with pedagogical implications, focusing on the art and techniques of counting, measuring, explaining, and understanding in facing or adapting to different sociocultural environments.

Mathematics is essentially born from cultural and environmental activities (Bishop, 2004). Mathematics exists within culture; it is embedded in, bound to, and influences culture (Dominikus, 2018). Matematika adalah suatu bentuk aktivitas manusia "*mathematic as a human activity*". Mathematics is a form of human activity: "mathematics as a human activity." Mathematics and culture are closely interconnected. The relationship between mathematics and local culture is very strong because learning mathematics requires a bridge between the discipline and its cultural context (Pulungan & Adinda, 2023).

Rumah Gadang is the traditional house of the Minangkabau people of West Sumatra. Its distinctive features include buffalo-horn-shaped roofs (*gonjong*), carved walls, and elongated structures. The house is not merely a residence but also a cultural symbol representing social status and the matrilineal system of the Minangkabau people. The ethnomathematical elements in the *Rumah Gadang* provide an interesting context for mathematics learning, as various mathematical concepts are found in its architectural design and philosophy(Fauzan et al., 2020).

The Minangkabau people are known for preserving their rich cultural heritage and traditions to this day. This can be seen in cultural products such as the architecture of the *Rumah Gadang*, the traditional *Randai* performance, Minangkabau songket weaving, and many others. The term *Rumah Gadang* literally means "big house." Its grandeur is reflected in its size, shape, function, and carvings, each of which bears symbolic meaning. The maximum length is 9 rooms, with 5 supporting pillars across its width, and the floor is 2 meters above ground level. The number of pillars determines the size of the building, while the door's position indicates the owner's lineage group. The *bilik* (chambers) serve as storage for valuable possessions. The carved panels on the front walls are reliefs that are chiseled and painted. The motifs of these carvings reflect the Minangkabau philosophy *Alam Takambang Jadi Guru* ("Nature as the Ultimate Teacher"), meaning the carvings' meanings correspond to natural laws and feature motifs of leaves, flowers, fruits, and animals from the natural world (Abdullah et al., 2015).

Rumah Gadang contains many geometric elements that can serve as learning materials in mathematics, especially through the ethnomathematical approach. The geometric elements of Rumah Gadang include both two- and three-dimensional shapes. The plane (2D) shapes found in the *Rumah Gadang* include: 1) Triangles (the gonjong roof resembles an isosceles triangle); 2) Trapezoids (the inward-slanting walls form trapezoids); 3) Squares and rectangles (used in windows, doors, and floors); 4) Rhombuses and circles (appearing in wall and pillar carvings). The solid (3D) shapes include: 1) Prisms and pyramids (the roof and main structure resemble rectangular prisms and pyramids); 2) Cubes and blocks (the body of the house resembles cubes or rectangular blocks); and 3) Symmetry and transformation (carvings and ornaments display reflectional and rotational symmetry)(Fitriza, 2019).

Significant developments in ethno mathematics have explored and integrated mathematical concepts from various cultures into education. One of the main approaches is the development of Culturally Situated Design Tools, web-based software applications that enable students to create simulations of cultural artifacts (Rosa & Orey, 2017; Xu & Ball, 2024). These tools help reveal mathematical knowledge embedded in traditional cultural designs such as beadwork, basket weaving, hairstyles, and even modern graffiti, enabling students to learn mathematical principles through their own cultural contexts (Rosa & Orey, 2017; Xu & Ball, 2024). Furthermore, smartphones have been explored as a way to integrate ethnomathematics and enhance students' learning experiences in mathematics classrooms.

However, most students do not realize that the ornaments in the Minangkabau Rumah Gadang contain elements of mathematical learning. Many believe that mathematics learning is separate from culture. As a result, learners become alienated from their own cultural heritage. One way to prevent this is by using virtual reality (VR) in the learning process. Through VR-based learning, students can experience another dimension that realistically presents objects similar to the real world, helping improve understanding and increasing learning interest and motivation (Choirin Attalina et al., 2024). The use of VR in education makes learning more enjoyable and boosts student motivation (Sholihin et al., 2020).

Many studies confirm that VR and AR significantly increase students' motivation and engagement in learning mathematics and reduce mathematics anxiety (Bertrand et al., 2024). The engaging and game-like environments created by immersive technologies encourage more meaningful learning experiences (Bertrand et al., 2024). These technologies are highly effective in supporting spatial reasoning and visualization, particularly for abstract mathematical concepts (Bertrand et al., 2024; Pahmi et al., 2023; Romero & Angeles, 2023; Su et al., 2022). Geometry and measurement are the topics most frequently investigated because VR/AR can realistically visualize 3D objects (Romero & Angeles, 2023). Research by Bertrand et al. (2024) mentions "Culturally Responsive Pedagogies" and the use of "storytelling and culture" in AR/VR activities, but this provides only an initial direction and has yet to position ethnomathematics as a central framework.

Thus, overall, we can see that the state of the art in this research specifically targets the use of immersive technologies (VR/AR) in ethnomathematics. By focusing on how VR/AR can be used to explore, understand, and teach mathematical concepts that originate from cultural contexts, it will not only contribute to a deeper understanding of ethnomathematics itself but also provide a new model for making mathematics education more inclusive, relevant, and engaging for students from diverse cultural backgrounds.

The use of VR in education will continue to transform how humans learn in the future. If the internet has enabled distance learning, VR provides an even more engaging remote simulation experience (Kurdi, 2021). For example, when visiting a traditional Minangkabau house, students no longer need to go on study tours; they can simply use VR equipment to visit the *Rumah Gadang* virtually. The development of VR, as cited by Kurdi (2021), began in 1962 with Morton Heilig's Sensorama prototype, designed to deliver a realistic film-viewing experience by engaging multiple senses: sight, hearing, smell, and touch. VR technology has since been applied in many industries, including entertainment, medicine, education, aviation, architecture, and the military. It is particularly useful for simulating scenarios that are difficult to replicate in real life.

VR is a computer-generated, immersive three-dimensional environment that can simulate both fictional and real-world settings, making it applicable across various fields (Elmqaddem, 2019). Currently, with the advancement of technology, VR has expanded into multiple domains and sectors, such as language learning (Hua & Wang, 2023), surgical education (Singh et al., 2015), cultural heritage (Chong et al., 2021), and sports training (Richlan et al., 2023). Based on previous research findings, this study will focus on mathematics and apply VR technology to mathematics learning grounded in the Minangkabau *Rumah Gadang* culture.

Virtual reality technology requires several components: realistic 3D visualization aligned with the user's perspective, and the ability to detect all user movements and responses, such as head or eye motion (Sukmawati et al., 2023). These features ensure that the graphics adjust according to changes in the user's 3D environment. According to Kurdi (2021), several key elements define the virtual reality experience: 1) Virtual world, a three-dimensional environment realized through media (rendering, display, etc.) where users can interact with others and manipulate objects; 2) Immersion, the perception of being physically present in a non-physical world, a sensation created by VR technology. Immersion is divided into three types: mental immersion (feeling mentally present in the virtual environment), physical immersion (feeling physical sensations from the virtual surroundings), and mental engrossment (being deeply absorbed in the virtual experience); 3) Sensory feedback; VR requires simulating as many human senses as possible, including visual, auditory, and haptic feedback; 4) Interactivity; the system must respond to user actions, allowing direct interaction within the virtual field.

The advantage of VR is its ability to create a strong sense of presence, making users feel as if they are truly inside the virtual environment. This allows visitors to explore a digital replica of the *Rumah Gadang* in a highly realistic way, as though they were at the actual physical location. This experience far surpasses what can be offered by photos, 2D videos, or even standard 360-degree videos (Slater & Sanchez-Vives, 2016), because VR actively responds to the user's head and body movements. In addition, VR eliminates geographical, physical, and financial barriers, allowing anyone to "visit" cultural heritage sites from anywhere in the world. It can even be the best option for visitors with health issues or those who have difficulty dealing with environmental factors (Othman et al., 2022). VR also facilitates a deeper understanding of architectural details and cultural context. Users can interact with the virtual environment, examine every detail, and understand the building's structure and layout from various perspectives and at a human scale. This capability is extremely helpful for understanding cultural values and historical construction processes that may be difficult to grasp solely from documents or images (Cardellicchio et al., 2024). Moreover, VR can be used to visualize architectural changes and development over time, allowing users to observe how the *Rumah Gadang* or other traditional buildings may have evolved across different historical periods (Hajirasouli et al., 2021).

Although not many specific studies on VR for the *Rumah Gadang* were found during the search, the concepts and advantages described above are highly relevant. Thus, VR opens a new dimension for experiencing and understanding cultural heritage, unmatched by other media.

The application used in this study to develop VR-based learning is Artsteps. Artsteps is a web-based and mobile digital platform that enables users to create, organize, and share 3D virtual exhibitions. It is suitable for art galleries, museums, education, and other creative presentations. Key features of Artsteps include: 1) VirtualSpace design: Users can create custom exhibition spaces by adding walls, floors, and decorative elements; 2) Upload Digital Content: Users can insert images, videos, text, 3D objects, music, and narration into the gallery; 3) Interactive Navigation: Visitors can freely explore the exhibition or follow a predetermined path; 4) Web and Mobile Access: The application is available via web browsers and Android/iOS apps; 5) Collaborative and Public Exhibitions: Creations can be shared publicly or kept private as needed.

This study discusses the development of a mathematics learning media based on ethnomathematics within the Minangkabau culture, utilizing virtual reality (VR). The cultural element used in this study is the architecture of the Minangkabau Rumah Gadang. So, the research questions can be formulated as follows: 1) How is the development process of ethnomathematics-based learning media assisted by Virtual Reality using the ADDIE model? 2) How feasible is the ethnomathematics-based learning media assisted by Virtual Reality in terms of the validity from content experts and media experts?3) How do students respond to the use of ethnomathematics-based learning media assisted by Virtual Reality in mathematics learning?

METHOD

Participants

This study aims to develop ethnomathematics-based learning media assisted by virtual reality that are valid, practical, and effective for use in the Mathematics Learning course. The participants in this study were two subject-matter expert lecturers, one media-expert lecturer, and 44 students (from one class) as the product trial sample. The trial sample was randomly selected from four classes (a total of 168 students) enrolled in the Mathematics Learning course in the even semester of the 2024/ 2025 academic year.

Research Design and Procedures

The research method chosen for this study is research and development (R&D), to develop an educational innovation in the form of an ethnomathematics-based mathematics learning media using virtual reality. The research and development stages follow the ADDIE model, which consists of five stages: analysis, design, development, implementation, and evaluation (Hess & Greer, 2016). Each stage is explained as follows: First, the Analysis Stage; it aims to identify the causes of the gap between expectations and reality, or problems in the learning environment. Once the causes of this gap are identified, potential solutions can be determined. The procedures carried out in this stage are: (1) Validation of the gap between expectations and reality; (2) Establishing development objectives; (3) Confirming development targets; (4) Identifying the needs required for development; (5) Determining the delivery system; and (6) Preparing the development implementation plan; second Design Stage; This stage aims to verify the expected objectives and appropriate testing methods. The steps include: (1) Preparing a list of components needed in the product; (2) Formulating the objectives of product development; (3) Designing instruments for product validation and testing; third Development Stage. In the development stage, the product from the previous stage is further developed and validated. The steps in this stage include: (1) Creating the product according to the design; (2) Selecting or developing supporting media; (3) Developing a user guide for students; (4) Developing a user guide for educators; (5) Conducting formative revisions; and (6) Carrying out preliminary trials; fourth Implementation Stage; In the implementation stage, the learning conditions are prepared to apply the developed product as a learning resource in the learning process; fifth Evaluation stage; At the evaluation stage, a one-group posttest-only design was used, in which students' learning outcomes were measured after the use of VR-based learning media. This design was chosen because it aligns with the objectives of development research, namely to test the feasibility and potential effectiveness of the product within a limited group. However, a limitation of this design is the absence of a control group and a pretest, which means the learning outcomes obtained indicate only the potential effectiveness of the media rather than providing strong causal evidence.

The product developed in this research is a learning medium based on ethnomathematics assisted by Virtual Reality (VR). The resulting press consists of two VR learning tools. The first medium discusses the concept of plane figures and their properties. This learning medium is used for two class meetings. The second medium covers finding the area of plane figures and is also designed for two class meetings. Both learning materials are installed on the students' Android devices before the lessons are conducted. The media contains problems, materials, assignments, and quizzes.

Instruments the instruments used for data collection include a material expert validation sheet, a media expert validation sheet, a practicality questionnaire related to the use of the product, and a student learning outcomes test. The expert validation instrument was developed based on the following indicators: (1) suitability with Course Learning Outcomes (CLOs) and teaching materials on plane figures; (2) integration of Minangkabau culture; (3) representation of VR images; (4) suitability and quality of evaluation; (5) effectiveness of VR media; and (6) students' learning interest. The instrument consisted of 24 positive statements, rated on a 4-point Likert scale (1–4), with all items formulated as positive statements. Meanwhile, the material expert validation instrument also consisted of 24 positive statements, rated on a 4-point Likert scale (1–4). The indicators included: (1) suitability between images and teaching materials; (2) visual and color design; (3) layout of components and materials as well as text readability; (4) representation of Minangkabau culture; (5) ease of application access; (6) clarity and arrangement of menu buttons; (7) operational stability of features and media performance; (8) communicative and interactive aspects; and (9) impact on learning motivation and understanding of the material. Next, statement items are created according to the formulated blueprint.

Before the subject-matter expert and media expert validation sheets were used in the study, they were first pilot-tested with one subject-matter expert lecturer and one media expert who were not part of the sample. The validity result obtained was 3.81, which was categorized as high validity, with several suggestions to revise some statement sentences to make them easier to understand. The purpose of the pilot test was solely to determine the readability level of the validation sheets (content validity), while reliability index analysis was not conducted. The subject-matter expert and media expert validation instruments were used only to assess content suitability and product feasibility. Therefore, these instruments did not require reliability testing, but only content validity (expert judgment), as recommended by Arikunto (2013) and Sugiyono (2015).

The next research instrument used was the Student Practicality Instrument. This instrument was a 24-item questionnaire using a 4-point Likert scale (1–4). The indicators used for the practicality instrument included: (1) suitability of the material with the learning objectives; (2) interactivity and flexibility in the use of the media; (3) text readability, language clarity, and communication; (4) visual design appeal; (5) representation of Minangkabau culture; (6) clarity and arrangement of menu buttons; (7) ease of media use; and (8) impact on learning motivation and understanding of the material.

Before the questionnaire was used as a research instrument, a pilot test was conducted on six students who were not included in the sample. The purpose of the pilot test was to assess the questionnaire's validity and reliability. Based on the pilot test results, the validity index was obtained by analyzing the correlation between each item and the total score using the Pearson Product-Moment correlation, yielding an r-value of 0.71; therefore, the questionnaire was considered valid. Meanwhile, the questionnaire's reliability was assessed using Cronbach's alpha, yielding an alpha of 0.78; thus, the instrument was considered reliable.

To demonstrate the contribution of the implemented product, a learning outcome test was administered to students after the learning process was completed. The test consists of 5 essay questions that measure cognitive abilities at levels C3, C4, and C5. The material being tested includes the basic concepts of geometric shapes, the properties of plane figures, and the area of plane figures, along with their learning process. An example of a question is: A teacher in West Sumatra wants to teach the concept of plane figures to 5th-grade elementary school students using the image of a *Rumah Gadang*. The teacher shows that the wall parts are rectangular and that the *gonjong* roof resembles an isosceles triangle. As a prospective teacher, you are asked to: a) Identify the plane figures found in the *Rumah Gadang* and explain their characteristics; b) Create a simple lesson plan that integrates the concept of plane figures with local culture.

Before the learning outcomes test was used as a research instrument, a pilot test was conducted on six students who were not part of the sample. The purpose of the pilot test was to examine the validity and reliability of the test. Based on the pilot test results, the validity index was obtained via item–total correlation using the Pearson Product-Moment correlation, yielding a calculated r of 0.84; therefore, the questionnaire was considered valid. The questionnaire's reliability was assessed using Cronbach's alpha, yielding an alpha of 0.76; thus, the instrument was deemed reliable. Consequently, the test was deemed appropriate for use as a research data-collection instrument.

Data Analysis

The data collected in this study were analyzed using qualitative descriptive methods.

Quantitative validation data were analyzed descriptively, while the validators' suggestions were analyzed qualitatively.

RESULT AND DISCUSSION

This study aims to develop a learning media based on Minangkabau cultural ethnomathematics integrated with virtual reality technology. The type of research is Research and Development (R&D). The research sample consists of students from the Elementary School Teacher Education Study Program at Bung Hatta University who are taking the Mathematics Learning course in the even semester of the 2024/2025 academic year.

The research method used in this study is research and development (R&D) to develop an ethnomathematics-based mathematics learning media through virtual reality. The research and development process follows the ADDIE model, which consists of five stages: analyze, design, develop, implement, and evaluate(Hess & Greer, 2016). As for the development stages of the ADDIE development model that have been carried out, they are as follows:

Analyze

At this stage, the researcher analyzed the needs in implementing culture-based (ethnomathematics) learning assisted by virtual reality technology in the Mathematics Learning course. This course is a new subject in the updated curriculum of the Elementary School Teacher Education (PGSD) Study Program. Since this is a new course, it is very difficult to find reference books that can serve as guides for both lecturers and students. Therefore, teaching materials are needed for students in the Elementary School Teacher Education Study Program (PGSD) who take the Elementary Mathematics Learning course.

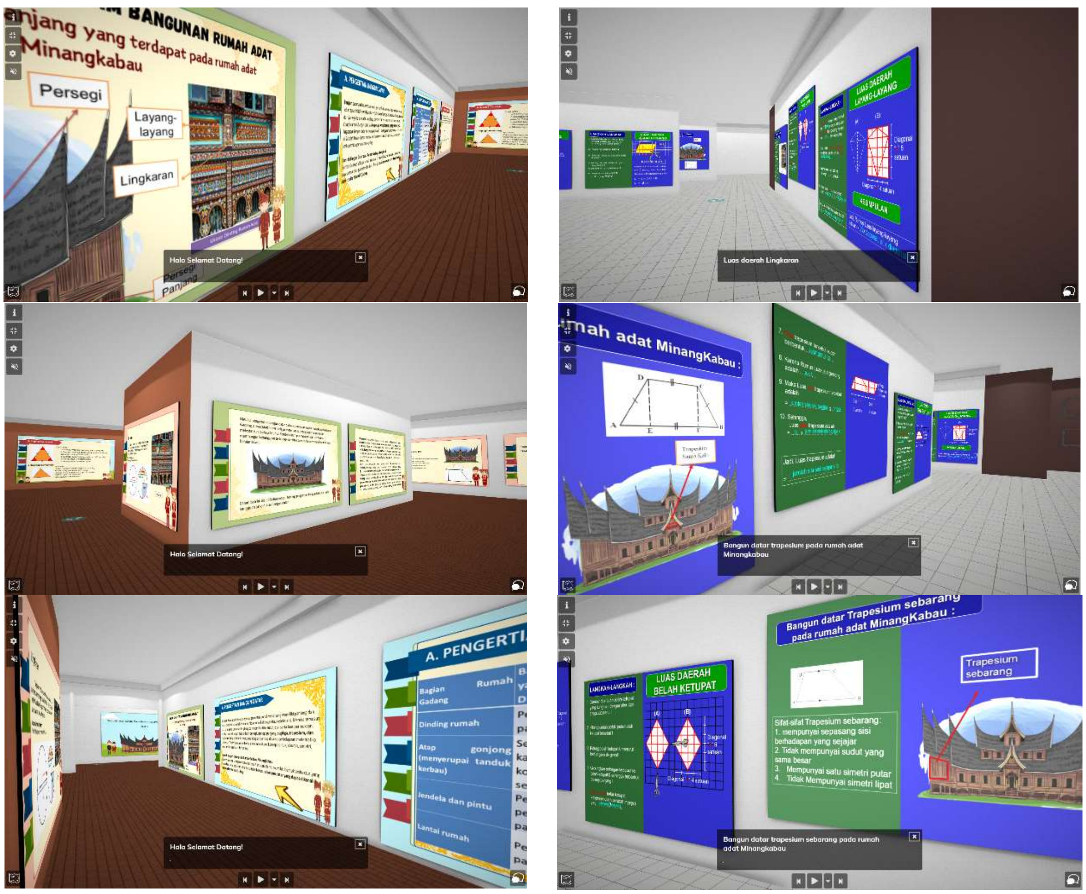
In addition, most PGSD students have low mathematical abilities. Based on observations of PGSD students, their mathematical ability was found to be low. This was evident when they were given math problems; only 10% achieved good scores (the "good" category is defined as a score equal to or greater than 65 on a 100-point scale). Furthermore, it was also found that most students were unfamiliar with Minangkabau culture. When asked about Minangkabau objects or customs, only 7% of students could identify them. If this continues, the Minangkabau culture could become extinct in its own region.

Therefore, a learning medium is needed that can improve students' mathematical abilities and their understanding of Minangkabau culture. The media developed in this research is an ethnomathematics-based learning media, supported by virtual reality, to enhance students' mathematical skills and cultural understanding. Based on various references, this media can improve students' mathematical abilities and their understanding of their local culture, namely the Minangkabau culture.

Next, a curriculum analysis was conducted. The topic to be developed is Two-Dimensional Shapes, with the course learning outcome (CLO) being that students are skilled in teaching two-dimensional shapes using virtual reality media. The indicators of learning achievement are designing learning steps to: 1) Explain the concept of two-dimensional shapes; 2) Describe the types/forms of two-dimensional shapes; 3) Distinguish the properties or characteristics of two-dimensional shapes; 4) Derive the area formulas of two-dimensional shapes; and 5) Solve problems related to two-dimensional shapes. Based on the results of the curriculum analysis and the lesson plan (RPS) for the Basic Mathematics Learning course, ethnomathematics-based learning media supported by virtual reality were then designed.

Design

The design stage aims to verify the expected objectives and the appropriate testing methods. The steps related to this design stage are as follows: First, designing teaching materials for ethnomathematics-based learning. The teaching materials are developed in accordance with the learning indicators established in the previous stage. These materials are based on ethnomathematics, using Minangkabau traditional culture, specifically the rumah gadang (traditional house) as the cultural basis. The elements of the Minangkabau rumah gadang are used as learning media for two-dimensional shapes, as many parts of the house structure represent geometric shapes that can be explored in learning about plane figures. Next, a Virtual Reality (VR) medium was created using the Artsteps application, available for download and installation from the Play Store. Using this application, a VR-based learning medium on two-dimensional shapes grounded in ethnomathematics was developed



a b

Figure 1. Interface examples of the virtual reality-based learning media developed for (a) basic concepts of planes and (b) area of planes

The instruments developed in this study consist of a Material Expert Evaluation Questionnaire, a Media Expert Evaluation Questionnaire, a Student Response Questionnaire, and students' mathematic score. The material expert questionnaire was given to three material experts, namely lecturers who teach Mathematics Learning courses. The media expert questionnaire was given to a media expert lecturer from the PTIK study program. Meanwhile, the student response questionnaire and the learning outcome test were administered to 44 students who participated in the mathematics learning activities. The purpose of the material expert validation is to ensure that the developed Virtual Reality Media aligns with the learning materials. The purpose of the media expert validation is to ensure that the developed Virtual Reality Media functions properly. The purpose of administering the student questionnaire is to understand students' perceptions of the learning process.

Develop

At this stage, development is carried out on the product designed in the previous stage, followed by its validation. The developed product is tested on the research sample. The product implementation was conducted over three sessions. The first session tested the first material, namely the concepts, types/forms of plane figures, and their properties; the second session covered the area of plane figures; and the third session involved distributing student evaluation questionnaires. Expert validation testing was conducted to determine the product's feasibility level, involving both material and media experts. The results of the material expert validation test were then used to improve the learning media materials developed. After the material expert validation test, descriptive data, including suggestions and improvements for the developed media, were also obtained. The results of the analysis of the validation questionnaires completed by the material expert validators can be presented as follows.

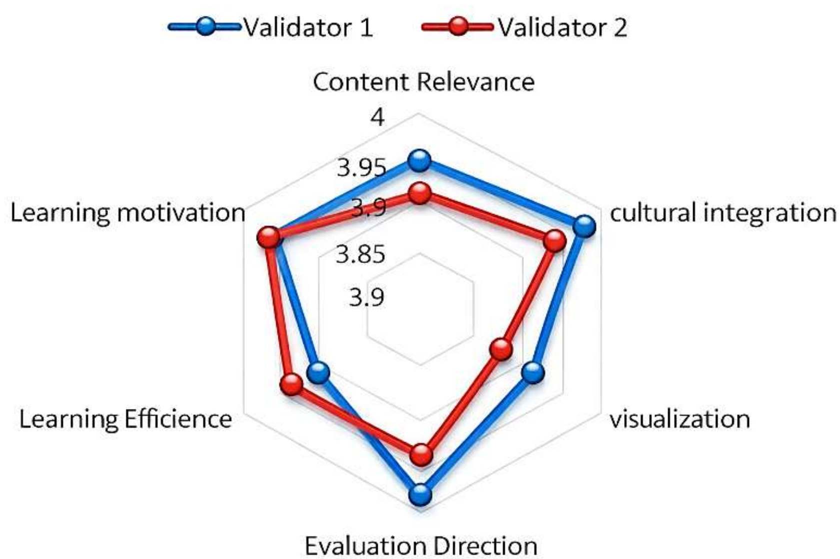


Figure 2. Validity result by material expert

The results of the subject-matter expert's questionnaire analysis indicate that the VR Flat Shapes learning media are highly feasible for use in mathematics instruction at the elementary education level. From the 20 statement items covering aspects such as alignment of the material with the Learning Outcomes (CPMK), integration of Minangkabau culture, clarity of presentation (visualization), evaluation instructions, learning efficiency, and learning motivation, an average score of 3.92 out of 4 was obtained. This indicates that the media meets the standards of content, structure, and relevant learning context. The subject matter expert also provided positive feedback on the use of the rumah gadang as a cultural context that enhances understanding of flat-shape concepts.

Furthermore, the results of the media expert validation test, along with the analysis of the validation questionnaire, are presented in Figure.

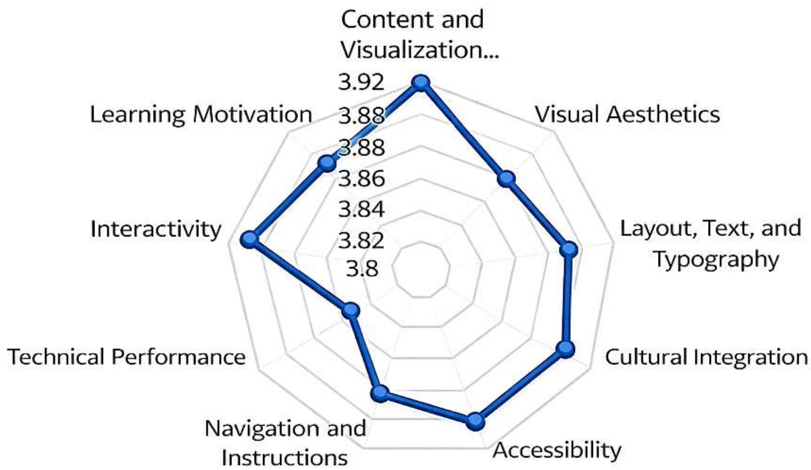


Figure 3. Result of data analysis by media expert

The assessment by media experts on the technical and visual design aspects of the VR media showed highly satisfactory results. Out of 25 statements covering content and visualization alignment, visual aesthetics, layout, text and typography, cultural integration, accessibility, navigation and instructions, technical performance, interactivity, and learning motivation, the average score was 3.89. The media was evaluated for its visually appealing design, intuitive navigation, and stable performance, without technical issues such as lag or crashes. In addition, the use of VR technology was considered capable of providing an immersive, innovative learning experience, motivating students to learn, and supporting the effective delivery of material for easy understanding.

In addition to providing quantitative assessments, the content expert validators and the media expert also provided qualitative comments. The comments from the three validators are summarized as follows. The first content expert validator suggested: (1) reconsidering the shapes of the parts of the *Rumah Gadang* to better represent plane geometric figures and adjusting them to align with the concept of plane shapes; and (2) making the concept of space more concrete in relation to the *Rumah Gadang*. The second content expert validator suggested: (1) reconsidering the planned time allocation, as the material was too extensive; and (2) improving the writing quality, as there were still several typographical errors. The media expert validator suggested: (1) adding a start button on the initial access screen, as the absence of such a button confused how to begin using the media; and (2) including a user manual or usage guidelines for students to help them understand how to operate the media.

Based on the validators' suggestions, the developed learning media were revised. The revisions included: (1) the trapezoidal shape in the *Rumah Gadang* was represented by the lower wall structure of the building, and one side that was previously not straight was corrected to better reflect a trapezoid; (2) the images used in the material on finding the area of a kite were not originally based on elements of the *Rumah Gadang* and were therefore adjusted to align with these elements; (3) two topics that were initially planned for two learning sessions were revised into three learning sessions; (4) all typographical errors were corrected; (5) a start button and a welcome message were added; and (6) a procedural manual was included.

Furthermore, the learning media were revised based on comments and suggestions from content and media experts and were piloted with students. This user testing aimed to determine students' responses to the Ethnomathematics-Based Learning media through virtual reality. At this stage, in addition to assessing the learning media product, students were also asked to provide comments and suggestions for further product development. The results of the completed student questionnaires can be presented as follows.

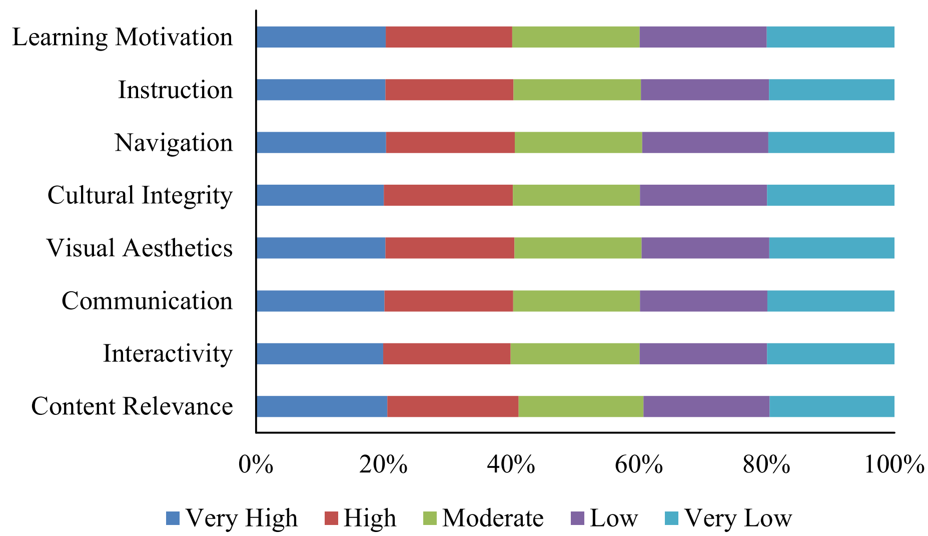


Figure 4. Results of the questionnaire by students

Students' responses to the use of VR learning media for Plane Figures were very positive. Out of 24 statements covering aspects such as content relevance, interactivity, communication, visual aesthetics, cultural integratity, navigation, instruction, and the impact on motivation and learning comprehension, an average score of 3.91 was obtained. Students found this media engaging, easy to use, and provided a learning experience different from conventional methods. They also appreciated the integration of Minangkabau culture into the media, which not only enriched cultural insight but also facilitated a contextual understanding of plane figure concepts.

To measure students' mathematical abilities after participating in the ethnomathematics-based Rumah Gadang learning media delivered through virtual reality, a test was administered. The test consisted of five essay questions and involved 44 students. The analysis of the test results was categorized based on the criteria proposed by Arikunto (2013) and Widoyoko (2014), which are applied at Bung Hatta University. Students' learning outcomes were classified into five categories: Very High (score range 80–100), High (66–79), Moderate (56–65), Low (40–55), and Very Low (0–39). The results indicated that 36.36% of students achieved a very high level of mathematical ability, 29.55% were in the high category, and 18.18% reached a moderate level. If mastery is defined as attaining the moderate, high, or very high categories, 84.1% of students passed the course, while 15.9% did not meet the mastery criteria.

Based on the analysis of students' learning outcomes in terms of the cognitive levels of the questions, the highest achievement was at the applying level (C3), comprising two items and yielding an average score of 78.5 and an achievement percentage of 85%. This was followed by the analyzing level (C4), also represented by two items, with an average score of 74.2 and an achievement percentage of 80%. Meanwhile, the evaluating level (C5), assessed by one item, yielded an average score of 70.1 and an achievement percentage of 75%. These results indicate that students' abilities tend to be stronger in applying concepts than in analyzing and evaluating them. Graphically, it can be illustrated as follows:

Figure 5 presents the distribution of students' learning outcomes by cognitive level as a 100% stacked bar chart. It can be seen that the largest contribution comes from level C3 (applying), followed by C4 (analyzing) and C5 (evaluating). This indicates that ethnomathematics-based VR media predominantly support the skill of applying concepts, while analytical and evaluative abilities (HOTS) remain relatively lower. This underscores the need for additional learning strategies to strengthen students' HOTS achievement. These findings align with the characteristics of the media: they are more effective at visualizing concrete concepts but require reinforcement of learning strategies to promote analytical and evaluative skills.

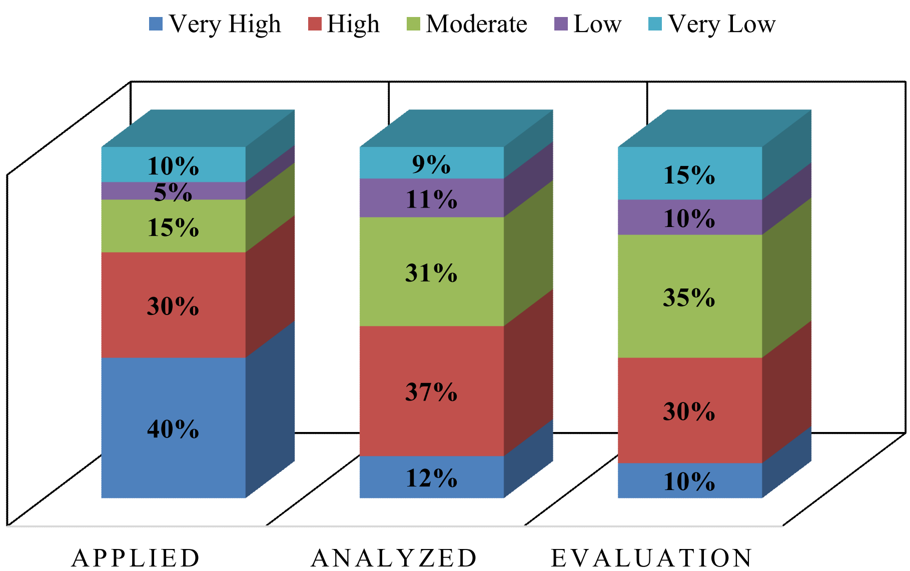


Figure 5. Students' achievement based on cognitive level

Overall, this analysis shows that the implemented learning strategies have successfully built a strong foundation of mathematical ability for the majority of students, while also creating opportunities for evaluation and development to more evenly enhance learning quality.

From the analysis of learning outcome data, it was found that students had not yet achieved the maximum score; 15.9% still obtained low or very low scores. This occurred despite the media validation score (97.7%) being very high and the student response score (3.91) also being very high. After conducting a product-moment correlation analysis between student response scores and learning outcomes, an r-value of 0.54 was obtained, indicating a moderate correlation. This indicates that high student response scores are not strongly correlated with students' learning outcomes. This is because the validation score reflects the design's quality according to experts, while the student response reflects the product's practicality. Meanwhile, learning outcomes are influenced by many factors, including students' initial abilities, math anxiety, and the complexity of ethnomathematics content. In addition, the items in the learning outcome test contained HOTS (C4, C5) levels without adequate support, leaving some students in the low and very low categories.

Based on the analysis of two questionnaires and the learning outcome test, it can be concluded that the Minangkabau culture-based Virtual Reality learning media for plane geometry material meets the criteria for validity and is practical to use, and has the potential to improve students' learning outcomes in terms of content, design, and users. This media is not only feasible for teaching mathematics but also capable of introducing local culture in an educational context. Therefore, this media is highly recommended for use in mathematics instruction at the elementary school level and in pre-service teacher education. Instructors can develop semester lesson plans that integrate ethnomathematics-based media with VR. The media can be designed gradually for geometry or symmetry topics and then expanded to other topics. It can also serve as a tool for out-of-class exploration to strengthen conceptual understanding.

Implement

At the implementation stage, learning conditions are prepared to apply the developed product as a learning resource in the learning process. After the learning activities, the trial subjects complete a practicality sheet regarding the product's use. The components assessed by the students include the following aspects: 1) language; 2) readability; 3) presentation; 4) appearance; 5) ease of use; and 6) usefulness.

The steps in the implementation stage are: 1) Preparing the Educator – The educator in this context is the researcher themselves, as a lecturer teaching the Elementary School Mathematics Learning course, who acts as the developer of the Ethnomathematics-Based Learning Media through Virtual Reality; 2) Preparing the Population and Sample – The population for the product trial consisted of students enrolled in the mathematics learning course in the Primary School Teacher Education program, encompassing four classes. For field testing, a trial sample of 30–100 participants is required (Sugiyono, 2015). Since one class taking the mathematics learning course consists of 44 students, the field-test sample was taken from one of the four classes in the population. The sample was selected using random sampling, with the consideration that the students in that class had a lower average GPA than those in the other three classes. 3) Time and Place of Research Implementation – The product implementation was carried out in May of the 2024/2025 academic year at the Elementary School Teacher Education program, Bung Hatta University.

Evaluate

At this stage, data on validation results, responses, and the practicality of the developed product are collected, analyzed, and summarized. This stage aims to determine the quality of the produced product.

The results of the study show that the ethnomathematics-based mathematics learning media that were developed successfully connected geometric concepts with local culture. The geometric concepts found in the *rumah gadang* include various plane figures located on the roof and wall carvings, such as squares, rectangles, kites, trapezoids, rhombuses, and circles. The concept of symmetry is also found in the reliefs of the *rumah gadang*. In addition, this VR media can enhance students' visual and kinesthetic engagement, in line with constructivist learning theory. This indicates that a culture-based learning approach (ethnomathematics) contributes to the development of mathematical thinking skills.

These results support the theory that mathematics cannot be separated from culture and can be found in the everyday practices of society (Auliya et al., 2024).

This learning media is highly relevant for students because it combines VR and culture, allowing students not only to learn through theory but also to experience an immersive environment that demonstrates the application of mathematical concepts in a cultural context. VR allows students to explore cultural objects, such as historical buildings or traditional motifs, while learning the mathematical elements in an engaging virtual environment. This learning media helps students understand mathematical steps systematically and continuously. This combination encourages active student engagement, strengthens their connection to the material, and helps students visualize practical applications of mathematical concepts in everyday life(Hasanah et al., 2024).

According to Buchori & Osman (2023), the use of VR-based mathematics learning media based on group investigations can increase students' curiosity. Students' curiosity rises when they access VR-based mathematics learning media grounded in group investigations and observe the engaging media display and diverse menu options.

The novelty of this study lies in using the rumah gadang as an ethnomathematical context for mathematics learning. The *rumah gadang* is positioned not only as a cultural object but also as a "geometry laboratory" rich in forms, patterns, and measurements. Its horn-shaped roof, arrangement of pillars, floor patterns, and carved motifs provide diverse representations of mathematical concepts, including plane and solid figures, measurement, symmetry, geometric transformations, number patterns, and ratios. An example of images of the parts of a Rumah Gadang to explain mathematics material is illustrated as follows.

This study developed mathematics learning media based on ethnomathematics using Virtual

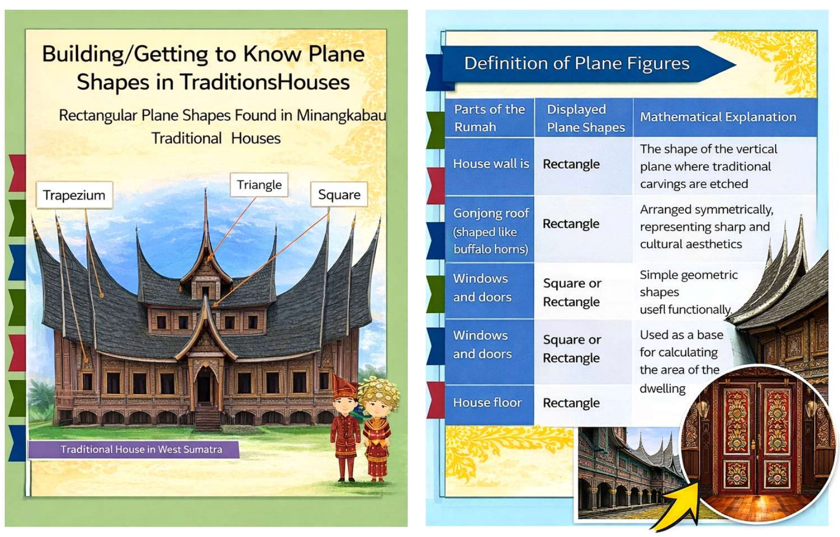


Figure 6. Examples of *rumah gadang* architectural elements used in mathematics instruction

Reality, meeting valid and practical criteria as assessed by experts and students. The trial results indicate that this media has the potential to enhance students' understanding of geometry concepts rooted in Minangkabau culture. However, because the evaluation stage employed a one-group posttest-only design, these findings provide only preliminary indications and cannot yet serve as strong causal evidence. Therefore, further research using a more rigorous experimental design (e.g., with a control group and a pretest) is needed to more comprehensively confirm the effectiveness of the media.

CONCLUSION

Based on the results of the research and discussion, it can be concluded that: 1) The mathematics learning media based on Minangkabau cultural ethnomathematics, developed through the ADDIE model, is feasible and practical for use in learning. This media integrates local cultural elements such as the geometric shapes of Rumah Gadang, carving motifs, and symmetrical patterns into mathematics material; 2) The Virtual Reality (VR) media used in the learning media can enhance students' engagement both visually and interactively. Students can explore Minangkabau cultural objects directly within a virtual environment that supports contextual understanding of mathematical concepts; 3) Students' responses to the learning media are very positive. Most students feel that the learning is more interesting, relevant, and motivating, encouraging them to learn mathematics in a way different from conventional methods.

Theoretically, the results of this study will have implications for mathematics learning, indicating that Minangkabau ethnomathematics-based learning media can make mathematics learning more concrete and provide an immersive learning experience, thereby increasing students' engagement, motivation, and positive responses. The findings of this study can also serve as a reference for academic programs in designing learning activities that help preserve the Minangkabau culture. Practically, the results of this study will also benefit lecturers as an innovative learning medium that can be used in instruction, benefit students by improving their learning outcomes, and provide opportunities for other researchers to further develop this medium, for example, for other topics or different educational levels. Equally important, the findings of this study also impact the community by contributing to the preservation of Minangkabau culture while remaining adaptive to global technology.

REFERENCES

Abdullah, M., Antariksa, & Suryasari, N. (2015). *Pola ruang dalam bangunan rumah gadang di kawasan alam surambi sungai pagu, sumatera barat* [Spatial pattern in the rumah gadang building in the surambi sungai pagu natural area, west sumatra]. *Jurnal Mahasiswa Jurusan Arsitektur Universitas Brawijaya*, *03*(01), 09.

Arikunto, S. (2013). *Dasar dasar evaluasi pendidikan [The basics of educational evaluation]*. Bumi Aksara.

Auliya, A. S., Hendikawati, P., & Niyamae, A. N. (2024). Development of STEAM-based ethnomathematics modules for enhancing students' problem-solving skills in social arithmetic. *Jurnal Pendidikan MIPA*, *25*(4), 1738–1751.

Bertrand, M. G., Sezer, H. B., & Namukasa, I. K. (2024). Exploring AR and VR tools in mathematics education through culturally responsive pedagogies. *Digital Experiences in Mathematics Education*, *10*, 462–486. https://doi.org/10.1007/s40751-024-00152-x

Bishop, A. J. (2004). The relationship between mathematics education and culture. *Iranian Mathematics Education on Kermanshah Iran*, 1–9.

Buchori, A., & Osman, S. (2023). Development of virtual reality math media in the junior high school Indonesia-Malaysia with group investigation model. *JRAMathEdu (Journal of Research and Advances in Mathematics Education)*, 1–11. https://doi.org/10.23917/jramathedu.v8i1.1547

Cardellicchio, L., Stracchi, P., & Globa, A.

(2024). Digital heritage construction/ : Testing the heritage value of construction documentation and building processes through virtual reality. *Frontiers of Architectural Research*, *13*(5), 1039–1055. https://doi.org/10.1016/j.foar.2024.02.012

Choirin Attalina, S. N., Efendi, A., Niswah, N., & Nugroho, V. A. (2024). *Efektivitas media pembelajaran berbasis virtual reality (VR) untuk meningkatkan kemampuan pemahaman materi pada siswa sekolah dasar* [The effectiveness of virtual reality (VR)-based learning media in improving elementary school students' comprehension skills]. *Jurnal Tunas Bangsa*, *11*(1), 31–43.

Chong, H. T., Lim, C. K., Rafi, A., Tan, K. L., & Mokhtar, M. (2021). Comprehensive systematic review on virtual reality for cultural heritage practices/ : coherent taxonomy and motivations. *Multimedia Systems*, *28*(3), 711–726. https://doi.org/10.1007/s00530-021-00869-4

Danoebroto, S. W. (2024). Teachers' efforts to promote students mathematical thinking using ethnomathematics approach. *Mathematics Teaching Research Journal*, *16*(2), 207–231.

Dominikus, W. S. (2018). *Literasi matematika Lamaholot*.

Elmqaddem, N. (2019). Augmented reality and virtual reality in education, myth or reality? *Int. J. Emerg. Technol. Learn*, *14*(3), 234–242.

Fauzan, A., Tasman, F., & Fitriza, R. (2020). Exploration of ethnomathematics at Rumah Gadang Minangkabau to design mathematics learning based on RME in junior high schools. *Proceedings of the 2nd International Conference Innovation in Education*, 279–283. https://doi.org/10.2991/assehr.k.201209.234

Fitriza, R. (2019). *Ethnomathematics pada ornamen rumah gadang minangkabau* [Ethnomathematics on the ornaments of the Minangkabau traditional house]. *Math Educa Journal*, *2*(2), 181–190. https://doi.org/10.15548/mej.v2i2.187

Hajirasouli, A., Banihashemi, S., Kumarasuriyar, A., Talebi, S., & Tabadkani, A. (2021). Virtual reality-based digitisation for endangered heritage sites: Theoretical framework and application. *Journal of Cultural Heritage*, *49*, 140–151.

Hasanah, N., Purnomo, E. A., & Mawarsari, V. D. (2024). Funethnomath: Development of virtual reality tour web learning media with an ethnomathematics. *MaPan: Jurnal Matematika Dan Pembelajaran, 12*(2), 274–293.

Hess, A. K. N. H., & Greer, K. (2016). Designing for engagement: Using the ADDIE model to integrate high-impact practices into an online information literacy course. *Communications in Information Literacy*, *10*(2), 264–282. https://doi.org/10.15760/comminfolit.2016.10.2.27

Hua, C., & Wang, J. (2023). Virtual reality-assisted language learning/ : A follow-up review. *Frontiers in Psychology*, *14*, 1153642. https://doi.org/10.3389/fpsyg.2023.1153642

Huang, W., Walkington, C., & Nathan, M. J. (2023). Coordinating modalities of mathematical collaboration in shared VR environments. *International Journal of Computer-Supported Collaborative Learning*, 163–201. https://doi.org/10.1007/s11412-023-09397-x

Kariadinata, R., Milah, A. M., & Sugilar, H. (2023). Development of interactive augmented reality multimedia based on ethnomatematics. *Jurnal Analisa*, *9*(1), 22–36. https://doi.org/10.15575/ja.v9i1.26032

Kurdi, M. S. (2021). *Realitas virtual dan* *penelitian pendidikan dasar: Tren saat ini dan arah masa depan* [Virtual reality and elementary education research: Current trends and future directions]. *CENDEKIA: Jurnal Ilmu Sosial, Bahasa Dan Pendidikan*, *1*(4), 60–85.

Marhami, M., Juandi, D., & Dasari, D. (2024). Indonesian students' numeracy skills based on PISA mathematical problems in secondary school: A meta-synthesis. *Jurnal Pendidikan MIPA*, *25*(July), 14–26.

Munir, M. (2019). *Strategi guru dalam problem based learning untuk meningkatkan penalaran matematika siswa* [Teacher strategies in problem-based learning to improve students' mathematical reasoning]. *De Fermat: Jurnal Pendidikan Matematika*, *2*(2), 103–108.

Nathal, K. L. P., Nathal, M. E. P., Bracamontes del Toro, H., Solano, M. A. G., & Sandoval, J. C. M. (2018). The immersive virtual reality/ : A study in three-dimensional euclidean space. *American Journal of Education*, *6*(3), 170–174. https://doi.org/10.12691/education-6-3-2

Nur, A. S., Kartono, Zaenuri, Waluya, S. B., & Rochmad. (2020). Ethnomathematics thought and its influence in mathematical learning. *MaPan: Jurnal Matematika Dan Pembelajaran*, *8*(2), 205–223.

Nur, A. S., Waluya, S. B., Rochmad, R., & Wardono, W. (2020). Contextual learning with ethnomathematics in enhancing the problem solving based on thinking levels. *Journal of Research and Advances in Mathematics Education* *5*(3), 331-344.

Orey, D. C., & Rosa, M. (2022). The role of Ubiratan D'Ambrosio and ethno mathematics to the development of social justice in mathematics education. *Mathematics Education*, *16*(January 2022), 52–71.

Othman, M. K., Altynai, N., Leong, L. S., & Barawi, M. H. (2022). Usability evaluation of a virtual reality smartphone app for a living museum. *Universal Access in the Information Society*, *21*(4), 995–1012. https://doi.org/10.1007/s10209-021-00820-4

Pahmi, S., Hendriyanto, A., Sahara, S., Muhaimin, L. H., Kuncoro, K. S., & Usodo, B. (2023). Assessing the influence of augmented reality in mathematics education/ : A systematic literature review. *International Journal of Learning, Teaching and Educational Research*, *22*(5), 1–25.

Prahmana, R. C. I., & D'Ambrosio, U. (2020). Learning geometry and values from patterns: Ethnomathematics on the batik patterns of Yogyakarta, Indonesia. *Journal on Mathematics Education*, *11*(3), 439–456.

Pulungan, N. A., & Adinda, A. (2023). E*ksplorasi etnomatematika dalam permainan tradisional kelereng daerah Padang sidimpuan Selatan* [Exploration of ethnomathematics in the traditional marble game of the South Padang Sidimpuan area]. *JURNAL MathEdu (Mathematic Education Journal)*, *6*(1), 21–28. https://doi.org/10.37081/mathedu.v6i1.4809

Purwanto, W. R., & Junaedi, I. (2025). Teachers ' perceptions of ethnomathematics learning in the independent curriculum program in Indonesia. *International Journal of Education and Practice*, *13*(1), 98–113. https://doi.org/10.18488/61.v13i1.3963

Putri, L. I., Retnawati, H., Jaedun, A., Murfi, A., & Atymtaevna, G. B. (2025). Enhancing mathematical skills through multicontextual approaches: A meta-analysis of realistic mathematics, ethnomathematics, and technology integration. *Cogent Education*, *12*(1). https://doi.org/

10.1080/2331186X.2025.2548648

Rahmawati, N. D., Rodliyah, I., Sa'adah, N., Ramadhani, R., Saraswati, S., Mufarrihah, I., & Khabibah, S. (2024). Revitalisasi matematika: *Problem based learning (PBL) bernuansa etnomatematika terhadap kemampuan berpikir kritis [Revitalizing Mathematics* [Problem-Based learning (PBL) with ethnomathematics as its nuance for critical thinking skills]. *Prosiding Seminar Nasional Sains, Teknologi, Ekonomi, Pendidikan Dan Keagamaan (SAINSTEKNOPAK)*, *8*, 1–7.

Richlan, F., Weiß, M., Kastner, P., & Braid, J. (2023). Virtual training, real effects: A narrative review on sports performance enhancement through interventions in virtual reality. *Frontiers in Psychology*, *14*, 1240790. https://doi.org/10.3389/fpsyg.2023.1240790

Romero, A. A., & Angeles, E. D. (2023). Flipped classroom in a digital learning space/ : its effect on the students' attitude toward mathematics. *International Journal of Learning, Teaching, and Educational Research*, *22*(1), 210–227.

Rosa, M., & Orey, D. C. (2017). Polysemic interactions of ethnomathematics: An overview. *ETD-Educação Temática Digital*, *19*(3), 589–621. https://doi.org/10.20396/etd.v19i3.8648365

Saphira, H. V. (2022). Integrating local wisdom-based learning to preparing the Pancasila students' profile, yes or no? *International Journal of Current Education Research*, *1*(1), 18–35.

Sholihin, M., Sari, R. C., Yuniarti, N., & Ilyana, S. (2020). A new way of teaching business ethics: The evaluation of virtual reality-based learning media. *International Journal of Management Education*, *18*(3), 100428. https://doi.org/10.1016/j.ijme.2020.100428

Singh, P., Aggarwal, R., Puncher, P. H., Hashimoto, D. A., Beyer-berjot, L., Bharathan, R., Middleton, K. E., Jones, J., & Darzi, A. (2015). An immersive '"simulation week"' enhances clinical performance of incoming surgical interns improved performance persists at 6 months. *Surgery*, *157*(3), 432–443. https:/ /doi.org/10.1016/j.surg.2014.09.024

Slater, M., & Sanchez-Vives, M. V. (2016). Enhancing our lives with immersive virtual reality. *Frontiers in Psychology*, *3*, 1–47. https://doi.org/10.3389/frobt.2016.00074

Su, Y., Cheng, H., & Lai, C.-F. (2022). Study of virtual reality immersive technology enhanced mathematics geometry learning. *Frontiers in Psychology*, *13*(February), 1–8. https://doi.org/10.3389/fpsyg.2022.760418

Sugiyono. (2015). *Metode penelitian dan pengembangan* [Research and development methods]. Alfabeta.

Sukmawati, F., Santosa, E. B., & Rejekiningsih, T. (2023). *Inovasi media pembelajaran virtual reality dalam pendidikan: Transformasi pendidikan era 5.0 [Innovation of virtual reality learning media in education: Transformation of education in the 5.0 era]*. Pradina Pustaka.

Supriyadi, E., Turmudi, T., Dahlan, J. A., & Juandi, D. (2024). Development of Sundanese gamelan ethnomathematics e-module for junior high school mathematics learning. Malaysian. *Malaysian Journal of Learning and Instruction*, *21*(2), 147–186.

Upasani, N., Manna, A., & Ranjanikar, M. (2023). Augmented,virtual and mixed reality research in cultural heritage/ : A bibliometric study. *International Journal of Advanced Computer Science and Applications*, *14*(1), 832–842.

Utami, N. W., & Sayuti, S. A. (2019). Math and mate in Javanese Primbon: Etno mathematics Study. *Journal on Mathematics Education*, *10*(3), 341–356.

Utami, W. B. (2019). Student experience about higher order thinking skill with contextual learning based ethnomathematics using learning media and math props. *International Journal of Recent Technology and Engineering*, *8*(IC2), 719–721.

Widoyoko, E. P. (2014). *Penilaian hasil pembelajaran di sekolah* [Assessment of learning outcomes in schools]. Pustaka Belajar.

Xu, H., & Ball, Ro. (2024). Multiple forms of knowing in mathematics: A scoping literature study. *ArXiv Preprint ArXiv*, *2406*(16921), 1–38.

Yazdi, A. (2025). Exploring the intersection of metaverse and mathematics/ : A visual analysis of bibliometric networks. *Discover Education*, *4*.