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Geometry learning innovation based on ethnomathematics-collaborative augmented reality to improve elementary school students' metacognitive abilities: A conceptual framework

I Nyoman Jampel[1], Ketut Herya Darma Utami[2], I Made Suarjana[3], Adrianus I Wayan Ilia Yuda Sukmana[4], Ni Wayan Suniasih[5], I Gede Wahyu Suwela Antara[6*]
[1,2,3,4,6]Universitas Pendidikan Ganesha, Singaraja, Indonesia; jampel@undiksha.ac.id (I.N.J.) darma.utami@undiksha.ac.id (K.H.D.U.) imade.suarjana@undiksha.ac.id (I.M.S.) aiwiy-sukmana@undiksha.ac.id (A.I.W.I.Y.) gede.suwela@undiksha.ac.id (I.G.W.S.A.).
[5]Pendidikan Ganesha, Singaraja, Indonesia; niwayan.suniasih@undiksha.ac.id (N.W.S.).

Abstract: This study aims to analyze and describe the conceptual framework of the integration between ethnomathematics and Collaborative Augmented Reality (CAR) in geometry learning to improve elementary school students' metacognitive abilities. The approach used in this study is qualitative with an exploratory design. The participants of the study were 20 elementary school teachers in Bali who were selected purposively, considering the rich Balinese culture and traditions as contextual sources for ethnomathematics. Data were collected through Focus Group Discussions (FGD) and in-depth interviews, then analyzed using thematic methods. The results showed that the integration of ethnomathematics, which includes contextual basis, analytical thinking, meaningful learning, and reflective awareness, with CAR, which emphasizes visual exploration, critical thinking, active learning, and collaborative problem solving, significantly contributed to improving students' metacognitive abilities, especially in the aspects of self-regulation and self-reflection. Ethnomathematics facilitates more contextual and meaningful geometry learning, while CAR supports visual exploration and collaboration in problem solving. The integration of these two approaches results in interactive and reflective learning, improving students' metacognitive thinking skills in the context of geometry learning. Teachers can apply ethnomathematics combined with Collaborative Augmented Reality to create interactive geometry lessons that enhance students' metacognitive self-regulation and reflection.
Keywords: *Collaborative augmented reality, Ethnomathematics, Geometry, Metacognitive abilities.*

1. Introduction

Metacognitive abilities play an important role in mathematics learning [1, 2], especially when studying geometry material at the elementary school level [3]. These abilities include students' awareness of effective learning strategies, understanding of their own thinking processes, and the ability to monitor and regulate their cognitive activities [4, 5]. Metacognitive abilities enable students to better understand basic geometric concepts, recognize patterns, and develop more efficient problem-solving strategies [6, 7]. In addition, metacognitive abilities also help students overcome difficulties and obstacles in understanding geometry material, as well as giving them the confidence to explore new ideas and face mathematical challenges more confidently [8] .

Problems that occur related to students' metacognitive abilities in learning mathematics, especially in geometry material in elementary schools, include students' lack of awareness of effective learning strategies, difficulties in organizing and monitoring their own thinking, and a tendency to rely on mechanical problem solving without understanding geometric concepts in depth [9, 10]. In addition, the lack of supporting learning media that are oriented towards metacognitive abilities is also a cause of low

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* Correspondence: gede.suwela@undiksha.ac.id

metacognitive abilities. The lack of access to learning aids that encourage reflection, self-monitoring, and interactive exploration of mathematical concepts can hinder the development of students' metacognitive abilities [11]. This causes geometry learning to tend to be passive and less stimulating, which in turn can limit students' understanding and interest in the material.

Problem-solving approaches that can be taken to overcome problems regarding students' metacognitive abilities in learning geometry material in elementary schools can be done with an innovative and integrated approach. The use of technology-based media can provide a good learning experience for students [12-14]. One approach that can be taken is to utilize augmented reality (AR) to create a more interactive and immersive learning experience for students [15, 16]. Students can visualize geometric concepts directly in real contexts, enabling them to explore more actively and understand the relationships between these concepts [17].

In addition, an approach that internalizes local values is also an interesting solution [17, 18]. This approach is known as ethnomathematics. It involves internalizing local cultural elements into geometry learning, enabling students to feel more connected to the material being studied and understand the relevance of mathematical concepts within their own cultural context. Students can develop their metacognitive abilities more effectively while increasing their interest and motivation in learning mathematics [19, 20].

Several previous studies have investigated the potential use of Augmented Reality (AR) technology in mathematics learning. These studies show that AR can increase students' engagement and understanding of geometric concepts through interactive and realistic visualizations [21, 22]. On the other hand, studies examining the application of the ethnomathematics approach in the context of mathematics education show that incorporating local cultural values into mathematics learning can increase students' interest, motivation, and understanding of the material [23-25]. Until now, there has been no research that specifically integrates the use of AR technology with the application of the ethnomathematics approach together in geometry learning at the elementary school level.

This study aims to analyze and describe the conceptual framework of the integration of ethnomathematics approaches with Collaborative Augmented Reality as an effort to improve elementary school students' metacognitive abilities. The integration of these two approaches can create a more interesting, meaningful, and contextual learning experience for students, while enriching their understanding of geometric concepts and their local cultural values. This innovation has the potential to create a stimulating and meaningful learning environment for elementary school students, where they can strengthen their understanding of geometry while developing metacognitive abilities effectively.

2. Review Related Literature

2.1. Metacognitive Abilities in Mathematics Learning

Metacognitive abilities are fundamental in mathematics learning as they enable students to plan, monitor, and evaluate their own thinking processes. These abilities encompass awareness of effective learning strategies, understanding of cognitive processes, and self-regulation of problem-solving activities [1, 26]. In the context of elementary geometry, metacognitive skills help students grasp abstract concepts, recognize patterns, and develop efficient strategies for solving problems [3, 27]. By fostering reflection and self-monitoring, metacognition empowers students to overcome difficulties, build confidence, and engage more meaningfully with mathematical challenges [8].

2.2. Challenges in Developing Metacognitive Abilities

Despite their importance, many elementary students struggle to apply metacognitive strategies in geometry learning. Common challenges include limited awareness of effective learning methods, difficulty organizing and monitoring their own thinking, and a reliance on rote problem-solving without deep conceptual understanding [9]. A significant contributing factor is the lack of learning media that specifically promotes reflection, self-regulation, and interactive exploration of geometric ideas [11, 28]. As a result, geometry learning often becomes passive and less stimulating, which constrains students' understanding and reduces their motivation to engage with mathematical content.

2.3. Technology-Based Media and Augmented Reality in Mathematics Education

To address these challenges, technology-enhanced learning media have emerged as promising tools for fostering metacognitive growth in mathematics education. Augmented Reality (AR), in particular, offers interactive and immersive experiences that allow students to visualize and manipulate geometric concepts in real-world contexts [29, 30]. Research indicates that AR can improve student engagement, support active exploration, and deepen conceptual understanding through dynamic visualizations of abstract mathematical structures [16, 30]. By bridging the gap between abstract theory and tangible experience, AR creates opportunities for learners to develop higher-order thinking and metacognitive skills.

2.4. Ethnomathematics and Culturally Contextualized Learning

Complementing technological approaches, ethnomathematics integrates local cultural values and practices into mathematics education to create meaningful and relevant learning experiences [31, 32]. Incorporating cultural contexts not only enhances students' appreciation of mathematical concepts but also strengthens their motivation and self-identity in learning [33, 34]. In Balinese settings, ethnomathematics enables students to connect geometry lessons with traditional art forms and community practices, promoting reflective awareness and deeper conceptual understanding [24].

2.5. Integrating Ethnomathematics and Augmented Reality

While previous studies have independently demonstrated the benefits of AR and ethnomathematics in mathematics learning [21, 22, 25], research combining these two approaches remains scarce, particularly in elementary geometry education. Integrating AR's interactive visualizations with ethnomathematics' cultural grounding offers a unique opportunity to create engaging, contextual, and metacognitively rich learning experiences. This integration holds the potential to enhance students' self-regulation and reflective thinking while simultaneously deepening their understanding of both mathematical concepts and their cultural heritage, thus laying the foundation for innovative and culturally responsive mathematics instruction.

3. Methods

3.1. Study Design

This study applies a qualitative approach with an exploratory design Miles, et al. [35] which aims to analyze and describe in depth the conceptual framework of the integration of ethnomathematics with Collaborative Augmented Reality (CAR) in geometry learning to improve elementary school students' metacognitive abilities. The exploratory design was chosen because it is appropriate for exploring a more comprehensive understanding of complex and under-researched phenomena, especially related to the synergy between augmented reality-based technology and local cultural elements in mathematics teaching. The use of qualitative methods provides an opportunity for researchers to be able to directly interact with participants who have experience and practical knowledge in this field of research, so that they can conduct in-depth data mining related to the perceptions, experiences, and challenges faced by participants [36].

3.2. Participants

Participants in this study were elementary school teachers in Bali who had experience teaching mathematics, especially geometry, and were interested in implementing technology-based learning innovations. The selection of participants was done purposively, considering their involvement in developing ethnomathematics-based learning and their experience in utilizing technology in teaching. Bali was chosen as the research location because of its rich culture and traditions, which offer many contextual materials to be integrated into ethnomathematics learning.

Table 1.
The origin of focus group discussion respondents.

No.	Area	Total number of teachers
1	Buleleng Regency	Three teachers
2	Bangli Regency	Two teachers
3	Jembrana Regency	Two teachers
4	Karangasem Regency	Two teachers
5	Klungkung Regency	Two teachers
6	Gianyar Regency	Two teachers
7	Tabanan Regency	Two teachers
8	Badung Regency	Two teachers
9	Denpasar City	Three teachers
Total		Twenty teachers

A total of 20 elementary school teachers from various districts in Bali participated in this study. The FGD involved all 20 teachers (Table 1), where they shared their views and experiences related to ethnomathematics-based geometry learning and CAR in two discussion sessions lasting 90 minutes each. Additionally, in-depth interviews were conducted individually with 5 selected teachers from the FGD participants, who were chosen based on their activeness in the discussion and further experience in using technology in learning (Table 2).

Table 2.
The demographic profile of the interview participants.

Name/Initials	Age (Years)	Length of teaching experience (Years)	School location	Educational qualification
T1	43	16	Buleleng	Master
T2	36	10	Gianyar	Master
T3	31	6	Tabanan	Bachelor
T4	30	6	Badung	Master
T5	30	5	Denpasar	Bachelor

3.3. Data Collection

Data collection in this study was conducted through Focus Group Discussions (FGD) and in-depth interviews. FGDs aimed to explore participants' views and experiences related to ethnomathematics-based geometry learning and the potential for CAR integration in the learning process. The discussions focused on identifying needs, challenges, and opportunities in implementing the two approaches in the classroom. FGDs were conducted in two sessions, each lasting 90 minutes. In-depth interviews were conducted individually to explore participants' perspectives on the implementation of ethnomathematics and CAR. The interviews also aimed to gain more personal information about teachers' readiness, their understanding of students' metacognitive abilities, and how they view the collaboration of technology and culture in geometry learning. Each interview lasted approximately 60 minutes and was conducted either face-to-face or online, depending on the participants' availability.

3.4. Instruments

The instrument used in this study was designed to explore teachers' views and experiences related to the integration of ethnomathematics with Collaborative Augmented Reality (CAR) in geometry learning, and how this approach can improve students' metacognitive abilities. The instruments used were Focus Group Discussion (FGD) guidelines and in-depth interviews, which were systematically arranged based on the research objectives. The FGD guidelines were designed to guide group discussions in exploring participants' understanding of the potential for integrating ethnomathematics and CAR in learning. One of the main aspects explored was how local Balinese culture can be utilized as a context in geometry learning. Meanwhile, the in-depth interview guidelines aimed to explore more deeply the teachers' personal experiences in implementing innovative methods in the classroom. One focus of the interview was how teachers assess students' metacognitive abilities in the context of ethnomathematics-based geometry learning. Examples of questions used as guidelines in the implementation of FGD and in-depth interviews are presented in Table 3.

Table 3.
Example of questions.

Data collection methods	**Aspect**	Example of questions
Focus group discussion	Ethnomathematics	How do you see Balinese culture and traditions being applied in teaching geometry through an ethnomathematics approach?
	CAR	What is your experience in using technology, such as Augmented Reality, in learning?
In-depth interview	Ethnomathematics	How do you observe the development of students' abilities in planning, monitoring, and evaluating their learning process when using local culture-based materials?
	CAR	What challenges do you face in combining local culture and technology in teaching? How do you overcome them?

3.5. Data Analysis

Data obtained from FGD and in-depth interviews were analyzed using a thematic analysis approach. This analysis process includes several stages, namely: (1) data transcription, (2) repeated reading, (3) initial coding, (4) identification of main themes, (5) grouping of themes, and (6) data interpretation. The data analyzed included teachers' views, experiences, and needs related to the integration of ethnomathematics and CAR in geometry learning. The analysis was carried out with the help of qualitative data analysis software to ensure accuracy and precision in data management.

3.6. Validity and Reliability

To ensure the credibility and validity of the data, triangulation methods were used by combining data from FGDs and in-depth interviews. In addition, member checking was conducted by asking participants to provide feedback on the interim analysis results presented by the researcher.

3.7. Ethical Consideration

This study has obtained ethical approval from the Research Ethics Committee, Ganesha University of Education, Indonesia. Throughout the research process, research ethical standards were strictly followed, including obtaining written consent from all participants through an informed consent process. Participants were given a detailed explanation of the purpose, procedures, and potential benefits of the study, as well as their right to withdraw at any time without any consequences. Confidentiality of participant data was ensured by using anonymous identification codes and storing data in a secure format. Participation in this study was voluntary, and no pressure or coercion was given to participants to participate in the study.

4. Results and Discussion Results

The integration of ethnomathematics with Collaborative Augmented Reality (CAR) in geometry learning has the potential to improve elementary school students' metacognitive abilities by creating contextual, reflective, and collaborative learning. Based on the results of the Focus Group.

Discussion (FGD) and in-depth interviews with five elementary school teachers in Bali revealed that the use of local culture-based ethnomathematics as a context in geometry learning, combined with CAR technology, can provide a more meaningful learning experience and actively involve students.

One of the teachers participating in the FGD stated, "*Using Balinese culture, such as symmetrical patterns in woven fabrics or temple structures, makes it easier for students to understand geometric concepts. They can see for themselves the application of what they learn in everyday life*" (Teacher 1, FGD). This statement

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reflects the contextual basis in ethnomathematics, where students learn geometry through the cultural context they are familiar with, making learning more relevant and meaningful. In addition, another teacher added, "*When students are faced with geometric problems that come from local traditions, they not only learn to solve mathematical problems, but also learn to analyze and understand the concepts behind them*" (Teacher 2, FGD). This shows that the integration of ethnomathematics can also stimulate students' analytical thinking through contextual and authentic problems.

From the perspective of CAR usage, teachers in the FGD revealed that this technology allows students to conduct visual exploration of geometric concepts that are difficult to understand abstractly. One teacher explained, "*With Augmented Reality, students can directly see the 3D shape of traditional Balinese buildings and analyze their proportions. This makes previously abstract concepts easier to understand*" (Teacher 3, FGD). This underlines the importance of visual exploration in CAR, which helps students understand geometry more concretely. In addition, the use of CAR also encourages students to think critically in solving the problems presented. Another teacher stated, "*When students work with the AR application, they have to find their own ways to solve the geometric problems given. This trains their critical thinking skills*" (Teacher 4, FGD).

In-depth interviews also showed that the integration of ethnomathematics and CAR played an important role in shaping students' reflective awareness. One of the interviewed teachers said, "*After learning the geometry concept through Balinese culture, I asked students to reflect on how they think in solving problems. This helped them become aware of their own thinking process*" (Teacher 5, Interview). This reflection shows how the teacher encouraged students to focus not only on the results but also on their thinking process, thus increasing their metacognitive awareness. Another teacher also noted that collaborative problem solving became more effective with CAR. "*Students worked together to solve the geometric challenges given through the AR application; they discussed, shared ideas, and solved the problems together. This greatly increased their engagement*" (Teacher 3, Interview).

The results of this study describe the conceptual framework of ethnomathematics and CAR integration that includes four main dimensions of each approach. From the ethnomathematics side, contextual basis and meaningful learning are achieved through the use of local culture in geometry learning, which not only provides a real context but also makes learning more relevant to students. Analytical thinking and reflective awareness also develop through exploration and reflection on geometric problems rooted in culture. Meanwhile, CAR provides opportunities for visual exploration of geometric concepts, which supports critical thinking, active learning, and collaborative problem solving. The integration of these two approaches allows for rich and dynamic learning, encouraging students' metacognitive development through structured, collaborative, and contextual activities. The conceptual framework of the integration between ethnomathematics and CAR is schematically presented in Figure 1.

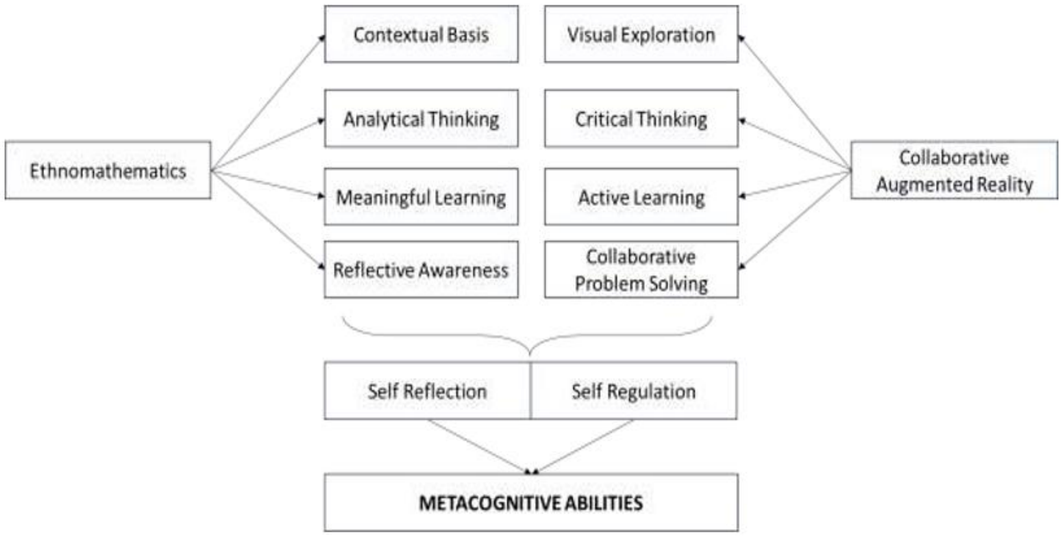

Figure 1.
Conceptual framework of ethnomathematics-CAR integration.

5. Discussion

The integration of ethnomathematics and Collaborative Augmented Reality (CAR) in geometry learning significantly contributes to improving elementary school students' metacognitive abilities. The findings of this study align with various previous theories and studies that emphasize the importance of contextual, collaborative, and technology-based learning in developing students' metacognitive thinking skills.

Ethnomathematics, as a context-based approach, provides students with the opportunity to understand geometric concepts through the exploration of relevant local cultures. As stated in previous studies, ethnomathematics learning utilizes cultural context to build contextual mathematical understanding so that it becomes more meaningful and relevant for students [32, 33]. In the context of this study, the integration of Balinese culture in geometry teaching, such as the use of symmetrical patterns on traditional fabrics and traditional building structures, enables students to connect geometric theory with real phenomena around them. This not only becomes meaningful learning but also stimulates students' analytical thinking. This process is in line with constructivist theory, where meaningful learning occurs when students can link new information to the knowledge they already have [37, 38].

The integration of ethnomathematics and CAR provides opportunities for students to plan, monitor, and control their own learning process, thereby improving self-regulation skills. Self-regulation refers to an individual's ability to actively regulate thoughts, emotions, and actions in an effort to achieve learning goals [39, 40]. Students are faced with the challenge of understanding and applying geometric concepts in a cultural context with the support of CAR technology that offers visual exploration. In addition, students are required to independently organize their strategies in solving geometric problems presented through AR applications. This can improve their critical thinking skills. This is in line with previous studies showing that virtual reality and augmented reality-based technology can improve students' metacognitive skills by providing a more interactive and exploratory learning experience, where students independently regulate their learning process [41, 42].

Mathematics learning by applying the ethnomathematics approach can also foster reflective awareness skills that encourage students to develop self-reflection, which is an important part of metacognitive skills. Self-reflection refers to students' ability to evaluate and reflect on their own thinking and learning processes [10, 43]. Through reflection, students can evaluate what strategies

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work and what do not in solving culture-based geometric problems. The use of CAR also strengthens this reflective process, where students are given the opportunity to re-observe the steps they took in visualizing geometry through AR, then discuss and evaluate the results collaboratively with their classmates. This is reflected in the research findings, where teachers stated that after using AR, students became more active in discussing and solving problems together, which strengthened their ability in collaborative problem solving.

The integration of active learning resulting from the use of CAR technology is also in line with previous studies showing that interactive technology-based learning increases student engagement in the learning process, facilitates more independent learning, and encourages students to be actively involved in monitoring their learning progress [44, 45]. Learning involving AR technology allows students to engage in exploratory tasks that require them to think critically and collaboratively in finding solutions, which is an important basis for developing self-regulation skills [46].

The integration of ethnomathematics with CAR creates a dynamic and immersive learning environment, where students can plan, monitor, and evaluate their own learning process within a rich cultural context. This finding supports previous studies that emphasize that a learning approach based on cultural context and utilizing modern technology can enhance students' metacognitive skills [11]. The concept of ethnomathematics, which emphasizes contextual learning and visual exploration that can be obtained from the use of CAR, serves as a catalyst for developing students' metacognitive skills, especially in terms of self-regulation and self-reflection, which are important in learning geometry in elementary schools.

6. Conclusion

The conclusion of this study indicates that integrating ethnomathematics and Collaborative Augmented Reality (CAR) in geometry education significantly enhances elementary students' metacognitive abilities, particularly in self-regulation and self-reflection. The conceptual framework based on these approaches demonstrates how contextual and interactive geometry learning can stimulate students' metacognitive thinking skills. Utilizing local culture within ethnomathematics, combined with CAR technology, offers a more relevant, concrete, and reflective learning experience. This approach not only deepens students' understanding of geometric concepts through cultural contexts but also encourages critical thinking, active visual exploration, and collaborative problem-solving. The integration of ethnomathematics and CAR fosters a learning environment that supports self-regulation, enabling students to independently plan, monitor, and evaluate their learning processes. Additionally, reflection-based learning through cultural contexts enhances self-reflection, inviting students to consider their thinking processes and strategies used in solving geometric problems. Consequently, the integration of ethnomathematics and CAR not only increases engagement in geometry learning but also equips students with essential metacognitive skills for future learning.

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Institutional Review Board Statement:

The study was conducted in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Ethical approval for this study was obtained from the Institutional Review Board of Ganesha University of Education, under approval number 104/UN48.24.11/LT/2024 dated 18 September 2024.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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