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Ethnomathematics-based augmented reality flip cards to enhance mathematical problem-solving skills in junior high school students

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Abstract

Background: The development of educational technology provides new opportunities to enhance the quality of mathematics learning, particularly in improving students' problem-solving skills.
Aims: This study aims to evaluate the effectiveness of ethnomathematics-based augmented reality flip cards integrated with Quizizz in improving junior high school students' mathematical problem-solving skills.
Methods: A design thinking approach was employed across five stages — empathize, define, ideate, prototype, and test — involving 178 students and five mathematics teachers from three junior high schools in Batang Regency. Data were collected through observation, questionnaires, and interviews, and analyzed using descriptive quantitative and qualitative thematic methods.
Result: The results indicate that ethnomathematics-based AR Flip Card integrated with Quizizz produced the highest effect size, with an ES value of 1.07.
Conclusion: This finding demonstrates that the integration of technology combined with ethnomathematics has strong potential to enhance mathematical problem-solving skills. Furthermore, the application of design thinking in mathematics learning development offers an effective and adaptive strategy for addressing continuously evolving educational challenges and fostering essential 21st century skills.

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INTRODUCTION

Mathematical problem-solving is widely recognized as one of the most essential competencies required in the twenty-first century, as it enables learners to analyze situations, think critically, and make evidence-based decisions in real-life contexts. Despite its importance, the mathematical performance of Indonesian students remains a significant concern. According to the Programme for International Student Assessment (PISA) 2022, Indonesia ranked 67th out of 81 participating countries, achieving a mathematics score of 366, which is substantially below the OECD average of 472. This persistent gap suggests that many students continue to struggle with higher-order mathematical thinking and problem-solving tasks. In Batang Regency, preliminary observations further indicate that approximately 78.7% of mathematics instruction is still dominated by teacher-centered approaches, characterized by lecture-based delivery and limited use of interactive learning media (S. Yanti, 2025; Zafitr, 2025). Such instructional practices may hinder students' opportunities to actively construct knowledge and develop problem-solving skills.

Students' difficulties in mathematics arise from a combination of cognitive and affective factors. From the cognitive perspective, many students experience challenges in understanding abstract mathematical concepts, retaining formulas, and applying systematic strategies to solve problems (Andriani, 2020; Angga et al., 2024). At the same time, affective factors such as mathematics

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anxiety significantly influence students' learning performance by reducing confidence, concentration, and willingness to engage with mathematical tasks. Previous studies have demonstrated that innovative learning environments, including technology-enhanced instruction, can reduce mathematics anxiety and improve learning engagement (Annisa, 2023). Furthermore, students often perceive mathematics as difficult, monotonous, and disconnected from their daily experiences, resulting in decreased motivation and participation in classroom activities (Anggraeni et al., 2022). The interaction between cognitive difficulties and negative emotional responses creates a cycle that further limits students' mathematical achievement and problem-solving development (A. H. Yanti, 2017).

In addition to student-related challenges, teachers encounter numerous barriers that affect the quality of mathematics instruction. Time constraints, large class sizes, curriculum demands, and limited access to innovative learning resources often restrict teachers' ability to implement student-centered pedagogies (Arifin, 2021; Dam & Siang, 2020). Another critical issue is the limited integration of contextual and culturally relevant learning experiences. Ethnomathematics, which connects mathematical concepts with local cultural practices and community knowledge, has been shown to improve conceptual understanding, learning motivation, and the relevance of mathematics education (Hafis, 2024; Lukman, 2022). Nevertheless, its implementation in classroom practice remains relatively uncommon. Recent educational developments also emphasize the potential of technology-mediated learning, particularly those incorporating culturally meaningful content, to enhance student engagement and mathematical understanding. Therefore, identifying both students' learning needs and teachers' instructional constraints is essential for designing learning solutions that are pedagogically effective, culturally responsive, and technologically relevant.

Although previous studies have extensively examined students' cognitive difficulties, mathematics anxiety, instructional barriers, ethnomathematics, and technology-assisted learning, these topics have generally been investigated separately. Existing research predominantly focuses either on students' learning challenges or on teachers' instructional limitations without examining how these factors interact within the same educational context. Consequently, there is limited empirical evidence regarding the alignment between students' actual learning needs and teachers' instructional realities in supporting mathematical problem-solving. Furthermore, few studies have systematically utilized such integrated needs analysis as a foundation for selecting or designing a technology-mediated instructional solution supported by evidence from prior intervention studies. This limitation creates a significant research gap in understanding how context-specific educational needs can inform the development of effective, culturally grounded, and evidence-based mathematics learning innovations.

This study aims to identify and analyze the primary challenges and learning needs of junior high school students and mathematics teachers in Batang Regency related to mathematical problem-solving. Furthermore, the study seeks to determine the most appropriate technology-mediated instructional solution for addressing these needs by synthesizing empirical evidence and effect-size findings from previous research. The results are expected to provide a comprehensive foundation for developing culturally relevant and technology-enhanced mathematics learning interventions that effectively support students' mathematical problem-solving competencies.

LITERATURE REVIEW

Mathematical problem-solving is widely recognized as one of the most important competencies required for successful participation in contemporary society because it enables individuals to analyze situations, evaluate alternatives, and make informed decisions in both academic and real-world contexts. In mathematics education, problem-solving is not merely an instructional objective but also a fundamental process through which learners construct and apply mathematical knowledge (Nilimaa, 2023; Olivares et al., 2021; Szabo et al., 2020; Verschaffel et al., 2020). Effective problem-solving requires students to understand the problem, identify relevant information, formulate appropriate strategies, execute solution procedures, and evaluate the correctness of their answers (Akben, 2020; Burkholder et al., 2020; Mahanal et al., 2022). These interconnected processes reflect higher-order thinking skills that extend beyond routine procedural performance. Students who possess strong problem-solving abilities tend to demonstrate greater flexibility in applying mathematical concepts to unfamiliar situations. Furthermore, mathematical problem-solving supports the development of critical thinking, logical reasoning, creativity, and decision-making skills that are essential for lifelong learning. Educational frameworks worldwide increasingly emphasize problem-solving as a key indicator of mathematical proficiency. However, many students continue to experience difficulties when faced with non-routine mathematical problems that require analytical reasoning rather than memorized procedures. Such difficulties often emerge when students lack opportunities to engage in meaningful problem-solving experiences during classroom instruction. Therefore, strengthening students' mathematical problem-solving skills remains a critical priority for improving the quality of mathematics education.

The development of mathematical problem-solving skills is influenced by numerous factors, including cognitive abilities, learning environments, instructional approaches, and sociocultural experiences. Among these factors, the connection between learning content and students' cultural backgrounds has received increasing attention in recent years. Learning becomes more meaningful when students can relate new knowledge to familiar experiences and cultural practices. Ethnomathematics offers an educational perspective that recognizes mathematics as a cultural product embedded within human activities, traditions, and social practices (Kabuye Batiibwe, 2024). Through ethnomathematics, mathematical concepts can be explored using local cultural artifacts, traditional architecture, handicrafts, games, and community practices (Kabuye Batiibwe, 2024; Loviana et al., 2026). This approach helps students understand that mathematics exists not only in textbooks but also in everyday life and cultural heritage. Previous studies have reported that ethnomathematics-based learning can improve conceptual understanding by presenting mathematical ideas within meaningful contexts. Students often demonstrate higher levels of motivation and engagement when mathematical content reflects their cultural identities and lived experiences. In addition, culturally responsive mathematics instruction contributes to the preservation and appreciation of local knowledge while simultaneously supporting academic achievement. Consequently, ethnomathematics has emerged as a promising strategy for enhancing students' mathematical learning experiences and problem-solving capabilities.

Research on ethnomathematics has consistently demonstrated its potential to improve various dimensions of mathematics learning, particularly conceptual understanding and problem-solving performance. By linking abstract mathematical concepts to culturally familiar situations, ethnomathematics reduces the cognitive distance between theoretical knowledge and practical application. Students are more likely to construct meaningful understanding when they encounter mathematical ideas through contexts that are relevant to their daily lives. This contextualization process supports knowledge retention and facilitates the transfer of learning to new situations. Furthermore, ethnomathematics promotes active participation because students are encouraged to explore and discuss cultural phenomena using mathematical reasoning (Asare, 2026; Danoebroto et al., 2024; Sari et al., 2023). Such learning experiences foster curiosity and create opportunities for collaborative problem-solving. Several studies have reported positive effects of ethnomathematics on students' attitudes toward mathematics, particularly in reducing perceptions that mathematics is difficult, abstract, or disconnected from reality (Asare, 2026; Batiibwe, 2025; Prahmana, 2022). Ethnomathematics also supports inclusive education by valuing diverse cultural backgrounds and recognizing multiple ways of understanding mathematical concepts. These characteristics align closely with contemporary educational goals that emphasize student-centered, contextual, and culturally responsive learning. Therefore, integrating ethnomathematical principles into mathematics instruction may provide an effective pathway for strengthening students' engagement and problem-solving competence.

Alongside culturally responsive pedagogies, technological innovation has become an increasingly important component of mathematics education in the digital era. Rapid advancements in educational technology have expanded opportunities for creating interactive and immersive learning environments that support deeper conceptual understanding. Among these innovations, Augmented Reality (AR) has gained considerable attention because it combines digital content with real-world environments in real time (Dargan et al., 2023; Syed et al., 2022; Turner, 2022). AR technology enables students to visualize abstract mathematical concepts through three-dimensional representations and interactive simulations. Such visualization capabilities are particularly valuable in mathematics because many concepts involve relationships that are difficult to comprehend through static text or images alone. Research has shown that AR-based learning can improve students' comprehension, engagement, motivation, and spatial reasoning skills (Aldeeb et al., 2024; Hung et al., 2023; Mokmin et al., 2024; Supli & Yan, 2024). In addition, AR environments encourage active exploration by allowing learners to manipulate virtual objects and observe immediate feedback from their actions. This interactivity supports constructivist learning processes in which students actively build their own understanding. The ability of AR to reduce abstraction and increase learner engagement makes it a promising tool for supporting mathematical problem-solving instruction. As a result, AR has become one of the most frequently explored technologies in contemporary mathematics education research.

Flip cards represent another instructional medium that has been widely used to facilitate active learning through concise, organized, and visually appealing presentations of information. Unlike traditional learning materials, flip cards encourage repeated review and self-paced learning, allowing students to engage with content more flexibly. When integrated with AR technology, flip cards can transform from static instructional tools into interactive learning media that support exploration and discovery. The incorporation of ethnomathematical content within AR-based flip cards further enhances their educational value by connecting technological innovation with cultural relevance. Through this integration, students can interact with culturally meaningful mathematical representations while simultaneously receiving visual support for abstract concepts. Such an approach has the potential to address multiple learning challenges, including conceptual difficulties, low motivation, and limited contextual understanding. Furthermore, AR-based ethnomathematical flip cards align with the principles of learner-centered education by promoting active participation and meaningful knowledge construction . The combination of visualization, cultural contextualization, and interactive engagement may create richer learning experiences than conventional instructional approaches. This integrated learning environment is expected to foster deeper conceptual understanding and more effective problem-solving strategies among students. Therefore, ethnomathematics-based Augmented Reality Flip Cards represent a promising instructional innovation for enhancing mathematical problem-solving skills among junior high school students.

METHOD

Research Design

This study employed a design thinking framework, a user-centered approach that emphasizes creativity and interdisciplinary collaboration, to facilitate the development of innovative and responsive solutions for addressing complex challenges in education. This iterative process has been shown to foster both creative problem-solving and user-centered thinking across educational contexts . Data collection integrated qualitative and quantitative methods: questionnaires and interviews for users' perspectives, and effect size calculations from prior studies to support solution selection at the ideate stage. This approach was selected because it is capable of generating learning solutions that are responsive to real conditions in the field (Khoirotunnisa et al., 2025; Lukman et al., 2024). The design thinking process consists of five main stages, namely empathize, define, ideate, prototype, and test, which are implemented systematically and iteratively to obtain optimal solutions (Harpeningtyas & Dwijayanti, 2025).

Participant

The participants in this study consisted of two main groups, namely students and teachers. A total of 178 students and 5 teachers from three junior high schools in Batang Regency participated in this study, namely SMP N 4 Batang, SMP N 5 Batang, and SMP N 1 Bandar. Participants were selected using purposive sampling, targeting schools with varied socioeconomic and infrastructural profiles in Batang Regency to ensure representativeness of the local educational context. The teacher sample, though limited to five individuals, was strategically selected to represent each participating school and to capture diverse instructional perspectives.

Instrument

The instruments used in this study included questionnaires, interview guidelines, and observation sheets. The questionnaires were used to collect quantitative data related to students' learning needs and difficulties, while the interview guidelines were used to obtain in-depth information from both students and teachers. Observation sheets were utilized to capture real classroom learning conditions. All instruments were validated by experts to ensure their content validity and appropriateness for use in the study.

Data Analysis

Data analysis in this study was conducted integratively by combining quantitative descriptive analysis and qualitative thematic analysis. The analysis process began with data reduction to select and simplify relevant data, followed by data display in the form of frequency tables and thematic matrices, and concluded with conclusion drawing to generate meaningful interpretations (Miles, Matthew B.Huberman, A. M.Saldaña, 2017). Data validity was ensured through source triangulation between students and teachers, as well as member checking to confirm that the researcher's interpretations aligned with the participants' perspectives. To support evidence-based solution selection at the ideate stage, effect sizes from relevant prior studies were calculated and compared using Cohen's formula. This quantitative comparison served to identify the most empirically supported instructional solution among the proposed alternatives, and should not be conflated with a formal meta-analysis, which requires systematic literature search protocols, inclusion/exclusion criteria, and heterogeneity analysis. The effect size was calculated using the following formula:

$$ES = \frac{\overline{x_E} - \overline{x_C}}{SD_C}$$

Description:
ES = Effect size.
$\overline{x_E}$ = Mean of the experimental group
$\overline{x_C}$ = Mean of the control group
SD_C = Standard deviation of the control group.
The effect size criteria adapted from Cohen are as follows:
$0,00 < ES \leq 0,20$: negligible

0,20 < ES ≤ 0,50 : low
0,50 < ES ≤ 1,00 : moderate
ES > 1,00 : high

Research Procedure

The research procedure began with the development of research instruments in the form of questionnaires and interview guidelines, which were then validated by expert lecturers to ensure content and construct validity. After the instruments were declared valid, observations were conducted to identify students' learning needs and difficulties directly in the field. The entire research process followed the stages of design thinking, starting with the empathize stage to understand students' experiences and challenges, followed by the define stage to formulate the main problems, the ideate stage to generate alternative solutions, the prototype stage to develop initial solution designs, and the test stage to evaluate the developed solutions.

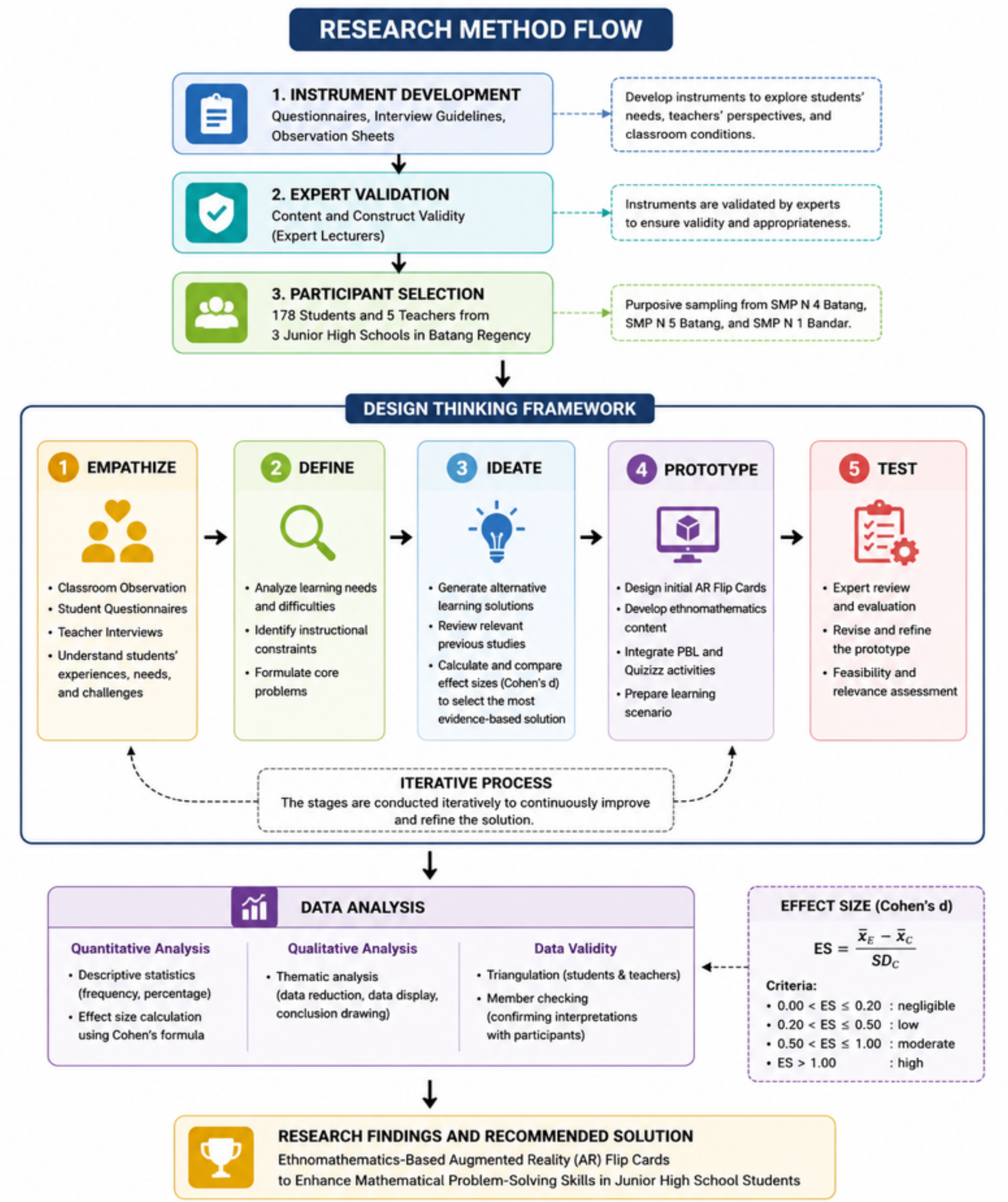

Figure 1. Research Method Flow.

RESULTS AND DISCUSSION

Results

The following section presents findings organized by key thematic categories derived from student and teacher data, followed by evidence-based solution selection and prototype design outcomes.

Empathize

The researchers collected primary data through semi-open questionnaires designed to explore the experiences, feelings, and perspectives of students and teachers. The student questionnaire contained 33 items addressing attitudes toward mathematics, learning difficulties, instructional preferences, and problem-solving experiences, while the teacher questionnaire comprised 25 items examining concerns, teaching challenges, implemented strategies, and professional development needs. This stage emphasized empathetic understanding without premature judgment, consistent with qualitative research principles that prioritize verstehen, or in-depth understanding (Mandala et al., 2025).

The data show that 66.3% of students experience difficulties in learning mathematics. The dominant challenges include understanding conceptual material (49%), interpreting problems (45.5%), and performing calculations (31.5%). In the planning stage, 61.8% of students immediately search for formulas without analyzing the problem. During implementation, students struggle with forgetting formulas (71.6%) and computational errors (64.6%). At the evaluation stage, only 8.5% consistently recheck their work, while 30.7% rarely do so, indicating weak mathematical problem-solving abilities. To gain an in-depth understanding of students' mathematics learning experiences and to capture teachers' perspectives on mathematics instruction, data from questionnaires and interviews were presented in the form of student and teacher empathy maps. Each empathy map encompassed four dimensions: Says (what is said), Does (what is done), Thinks (what is thought), and Feels (what is felt).

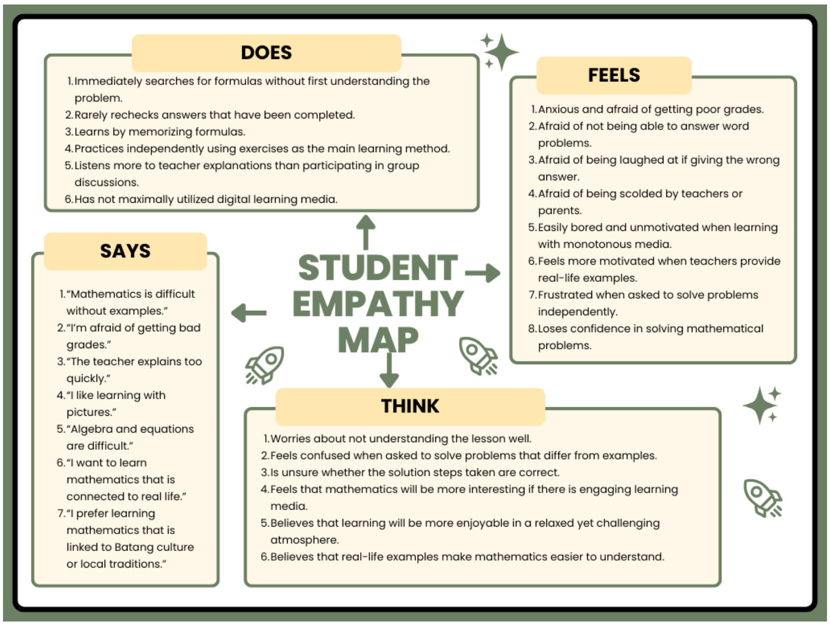

Figure 1. Student Empathy Map

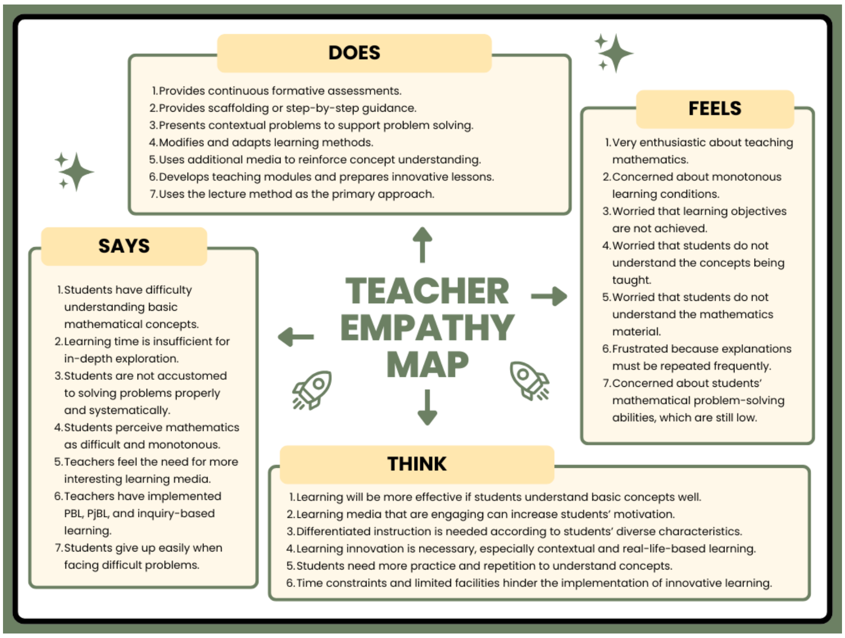

Figure 2. Teacher Empathy Map

The analysis of classroom instructional practices reveals several significant constraints that affect the effectiveness of student learning. The dominant instructional method used is lecturing or direct explanation by the teacher (78.7%), followed by independent problem-solving exercises (48.9%) and classroom question-and-answer sessions (33.7%). This dominance of the lecture method aligns with students' complaints that teachers' explanations are delivered too quickly (45.5%), indicating a mismatch between the pace of instruction and students' ability to process information.

In terms of learning media, 41.6% of students reported that they had never used digital media in learning mathematics. This condition contrasts with students expressed needs for learning that utilizes digital and interactive media (59%), game-based media (43.3%), and manual-based media (65.2%). To facilitate clearer understanding, the instructional methods and learning models currently used by teachers and those desired by students are presented in Table 1 (Lutfiyana & Purwosetiyono, 2025).

Table 1. Instructional Methods and Models Used Compared to Those Desired by Students

Aspect	Category	Frequently Used	Desired by Students
Learning Methods	Lecture / direct explanation	78,7%	68,5%
	Independent problem-solving exercises	48,9%	24,7%
	Group discussion	6,2%	18,5%
	Problem-Based Learning (PBL)	-	21,3%
	Enjoyable learning media	-	5,6%
Learning Media	Concrete teaching aids	47,2%	65,2%
	Never used digital media	41,6%	-
	Learning videos	1,1%	29,8%
	Game-based applications (Kahoot/Quizizz)	10,7%	37,6%
	Interactive digital media	5,1%	59%

In an effort to address these constraints, all teachers (100%) provided graduated exercises and step-by-step scaffolding, as well as acknowledging contextual problems to support students' problem-solving. Additionally, 75% of teachers reported modifying or adapting instructional methods and using supplementary media to clarify concepts. Nevertheless, learning outcomes indicate that only a portion of students are able to solve problems effectively. This finding suggests that there remains significant room for improvement in the instructional strategies currently implemented

Define

The second stage is define, in which the collected data are systematically analyzed to identify key patterns of constraints and needs. The analysis was conducted through frequency tabulation for closed-ended data and thematic analysis for open-ended data, followed by a qualitative meta-analysis to synthesize findings across categories. This process resulted in clearly defined and measurable problem statements. An interesting finding is that 83.1% of students had never connected mathematics with local culture such as batik, carvings, or regional traditions, even though 39% of them expressed a desire for an ethnomathematics-based approach in learning. The define stage aims to identify core needs and deep insights from students and teachers based on the collected empathy map data. The resulting points of view (POV) derived from the identification of students' and teachers' needs are as follows:

Table 2. Student Point of View

Student Point of View		
Needs	1	Students need more practice problems, especially contextual ones.
	2	Students need visualizations to support understanding of abstract concepts.
	3	Students want interactive digital learning media.
	4	Students need game-based or quiz-based learning activities.
	5	Students need to develop the habit of checking their answers.
	6	Students need learning that incorporates Indonesian culture / ethnomathematics.
Insight	1	Students feel that mathematics learning is still more focused on memorization rather than conceptual understanding.
	2	Students perceive that contextual learning has begun to be implemented, but it has not yet addressed the ethnomathematics dimension.
	3	Students feel that their reflective and self-evaluation skills are still very low.
	4	Students believe that a combination of digital learning media is needed.

Based on Table 2, there is a clear tendency toward the need for more meaningful mathematics learning through visual approaches and digital interaction linked to ethnomathematical contexts. This indicates the urgency of shifting from traditional rote-learning methods toward a more comprehensive conceptual understanding. These efforts should be accompanied by the development of self-evaluation skills to enhance students' accuracy and independence in the problem-solving process.

Table 3. Teacher Point of View

Teacher Point of View		
Needs	1	Teachers need better access to learning media.
	2	Teachers need interactive digital media and educational games.
	3	Teachers need instructional models that develop systematic problem-solving skills.
	4	Teachers need more contextual and real-life–based approaches.
	5	Teachers need greater variation in teaching methods beyond lecturing to increase student engagement.
Insight	1	Teachers feel that they have not yet found learning media that appropriately match students' needs.
	2	Teachers feel that the scaffolding provided may not yet be well targeted.
	3	Teachers believe that the instructional models used so far are not sufficient to improve students' abilities.

4	Teachers feel open to and demonstrate a high level of readiness for change.

The main constraint in learning does not lie in teachers' reluctance to change, but rather in limited access to innovative learning media that align with students' needs. Teachers recognize that conventional methods and the existing scaffolding approaches are no longer sufficient. Based on the needs and insights identified from both students and teachers, a set of How Might We (HMW) questions was formulated as a bridge to the ideate stage:

1. How might teachers prepare engaging learning experiences? By developing learning media that are relevant and aligned with students' needs.
2. How might interactive digital media be integrated with concrete teaching aids in mathematics learning? By developing AR-based media that can be presented in both digital and concrete forms.
3. How might game-based learning be designed to be not only enjoyable but also meaningful? By utilizing web-based or game-based learning platforms, or by independently developing game-based learning media.
4. How might students' habits of checking and evaluating their problem-solving processes be fostered? By implementing problem-based learning or ethnomathematics-based approaches.
5. How might differences in students' learning pace be accommodated without causing faster learners to feel bored or slower learners to fall behind? By applying differentiated instruction.

Ideate

The ideate stage involved developing three alternative solution ideas based on the analysis of constraints and needs that had been defined. Each idea was developed by considering aspects of implementation feasibility, potential effectiveness, and suitability to the junior high school context in Batang Regency. Subsequently, a meta-analysis was conducted on the three ideas by calculating effect sizes from relevant previous studies and examining their alignment with the questionnaire findings in order to determine the idea most consistent with the research title (Yanti, 2025).

The ideate stage produced alternative learning solutions that are responsive to the identified needs and insights. Each idea was subsequently evaluated through meta-analysis to determine the most appropriate option for the research context. The resulting ideas are as follows:

1. Ethnomathematics-Based AR (Augmented Reality) Flip Card Integrated with Quizizz to Improve Mathematical Problem-Solving Skills
2. Pure Gamification-Based Digital Learning Media (Mobile Mathematics Game Application)
3. Differentiated Instruction with an Ethnomathematics Approach

The integration of Quizizz with an ethnomathematics nuance within a PBL framework has been demonstrated to significantly enhance students' critical thinking and problem-solving processes (Annisa et al., 2023). Qualitative meta-analysis in this context was used to synthesize findings from various primary data sources collected through semi-open questionnaires, thereby generating a more comprehensive understanding of consistently emerging patterns of constraints and needs. To determine the best idea, a meta-analysis was conducted on previous studies relevant to each proposed idea.

Tabel 4. Research Data for Effect Size Calculation

Code	Study	Treatment	N	Effect Size (ES)
Idea 1: Flip Card AR + Quizizz + Etnomatematika + PBL				
A1	Hafis (2024)	AR to improve conceptual understanding	30	1,05
A2	Astuti (2022)	Quizizz for problem-solving skills	30	1,12
A3	Andriani (2020)	Ethnomathematics for conceptual understanding	20	1,04

A4	Hapsari (2021)	PBL for problem-solving ability	24	1,10
		Idea 2: Pure Gamification (Mobile Game)		
B1	Juang (2025)	Mobile games to enhance learning motivation	29	0,59
B2	Yani (2023)	Gamification for mathematics learning outcomes	27	1,23
		Idea 3: Differentiated Instruction + Ethnomathematics		
C1	Sianturi (2025)	Differentiated instruction for critical thinking	28	0,95
C2	Kusuma (2025)	Ethnomathematics for critical thinking skills	30	0,78

Tabel 5. Effect Size Value for Each Proposed Solution

Ide Solusi	Effect Size	Kategori
Ide 1: Flip Card AR + Quizizz + Etnomatematika + PBL	1,17	High
Ide 2: Pure Gamification (Mobile Game)	0,91	Moderate
Ide 3: Differentiated Instruction + Ethnomathematics	0,87	Moderate

Based on Table 5, it can be seen that Idea 1 (AR Flip Card + Quizizz + Ethnomathematics + PBL) has the highest effect size of 1.07 (high category). In contrast, Idea 2 has an effect size of 0.91 (moderate), which is lower than Idea 1 because it does not integrate problem-based learning components. Meanwhile, Idea 3 has an effect size of 0.87 (moderate), which is relatively good but not as effective as Idea 1 in improving problem-solving skills. Therefore, the best alternative solution is Idea 1, namely an ethnomathematics-based AR Flip Card integrated with Quizizz using the Problem-Based Learning (PBL) model to improve mathematical problem-solving skills.

Prototype

The stages of prototype design development were carried out immediately after the phases of data collection, idea generation, and solution exploration had been completed. As a fundamental component of user-centered design thinking, prototype development enables designers to test and refine ideas effectively within a short time frame (McLaughlin, 2022). However, planning the trial of these ideas must take into account various critical variables, such as curriculum alignment, infrastructure availability, funding, school environmental conditions, human resource capacity, as well as energy and time efficiency (Maulana et al., 2023). The main design to be developed involved an ethnomathematics-based AR Flip Card integrated with Quizizz and engaged 22 participants, consisting of three experts in mathematics education and 19 postgraduate students, through Focus Group Discussions (FGDs). The development of the ethnomathematics-based AR Flip Card with Quizizz resulted in prototype models comprising: (1) an ethnomathematics-based AR Flip Card learning media; (2) evaluation media using Quizizz integrated with the learning media; and (3) a mathematical problem-solving test instrument.

The development of the ethnomathematics-based AR Flip Card with Quizizz was comprehensively designed to address various challenges in mathematics learning by integrating technology with local wisdom. This aligns with recent innovations in AR-based culturally integrated mathematics teaching that demonstrate enhanced student engagement and problem-solving performance (Nagari et al., 2025). To meet the high demand for interactive digital media and game elements, physical Flip Cards were used as concrete teaching aids, providing a hybrid learning experience that harmoniously combines digital and physical interaction. Furthermore, ethnomathematical aspects were incorporated through the integration of Batang local culture, which most students had not previously encountered (Training, 2025; C. Wang, 2024; Wiesner, 2022). From a cognitive perspective, 3D visualization was employed to concretize abstract mathematical concepts in order to overcome difficulties in conceptual understanding, while the questions on the Quizizz platform were structured progressively to train students' mathematical problem-solving skills, particularly for students who had previously experienced confusion in applying various problem-solving strategies (Siregar et al., 2025).

Testing

The testing plan was carried out using four methods: (1) an expert media validation sheet for the ethnomathematics-based AR Flip Card media; (2) a student response questionnaire; (3) a mathematical problem-solving test; and (4) classroom observation. The expert validation sheet ensured that the media design aligned with pedagogical objectives. The student questionnaire provided direct insights into students' experiences and the perceived benefits of the media design. The mathematical problem-solving test offered an overview of students' abilities to solve problems in a systematic manner, while observational data helped capture student interactions and responses during the learning process. Overall, these instruments provided a comprehensive picture of the prototype's quality, student engagement, and its potential to enhance mathematical problem-solving skills

Discussion

The findings indicate that the difficulties experienced by junior high school students in Batang Regency are rooted not only in deficiencies in mathematical knowledge but also in long-standing instructional patterns that emphasize procedural fluency over analytical reasoning. The observation that 61.8% of students immediately searched for formulas without first analyzing the problem demonstrates a tendency toward algorithmic thinking rather than genuine problem-solving. This finding suggests that students have become accustomed to viewing mathematics as a collection of procedures to be memorized rather than concepts to be understood. Similar patterns have been reported in previous studies, which found that students frequently rely on memorized solution pathways when confronted with unfamiliar mathematical tasks (Kenney & Ntow, 2024; Nilimaa, 2023; Ye et al., 2024). Research on mathematical cognition has consistently shown that excessive procedural instruction limits students' ability to transfer knowledge to new situations. The present findings therefore support the argument that effective problem-solving instruction requires explicit opportunities for students to analyze, interpret, and reflect on mathematical situations. Furthermore, the absence of visual and contextual learning resources appears to reinforce students' dependence on formulas and routine procedures. This interpretation is consistent with studies showing that contextualized and visually supported learning environments promote deeper conceptual understanding. Consequently, improving mathematical problem-solving skills requires instructional approaches that move beyond procedural repetition and encourage conceptual reasoning. The proposed ethnomathematics-based AR Flip Cards directly address this need by integrating visualization, contextualization, and active engagement within the learning process.

The study also revealed a substantial discrepancy between teachers' awareness of instructional limitations and their actual classroom practices. Although all participating teachers acknowledged the need for more innovative teaching methods, classroom instruction remained largely lecture-centered. This finding highlights the influence of systemic and contextual constraints on pedagogical decision-making. Similar results have been reported in educational research indicating that teachers often support student-centered learning in principle but encounter practical barriers during implementation (Awacorach et al., 2021; Fufa et al., 2023; Martin-Alguacil et al., 2024; Soubra et al., 2022; Zhang et al., 2021). Curriculum coverage requirements, limited instructional time, large class sizes, and inadequate access to educational media are frequently cited as major obstacles to pedagogical innovation. As a result, teachers may continue to rely on conventional methods even when they recognize their shortcomings. The persistence of teacher-centered instruction contributes to reduced student participation and fewer opportunities for collaborative problem-solving. Previous studies have demonstrated that interactive learning environments are more effective than lecture-based approaches in promoting critical thinking and mathematical reasoning (Imran et al., 2022; Khasawneh et al., 2023; Ssemugenyi, 2023; Ulfa et al., 2021; Q. Wang & Abdullah, 2024). Therefore, interventions designed to improve mathematical problem-solving must consider not only student needs but also the realities of teachers' instructional contexts. The use of AR Flip Cards offers a practical alternative because the media can be integrated into existing classroom structures without requiring substantial changes to curricular content or instructional schedules.

One of the most significant findings of this study is that 83.1% of students reported never encountering mathematics learning connected to local cultural contexts. This result suggests that mathematics instruction remains largely detached from students' sociocultural experiences. Ethnomathematics scholars have long argued that culturally responsive learning environments enhance students' ability to construct meaning from abstract mathematical concepts. By linking mathematics to familiar cultural artifacts, traditions, and community practices, students are better able to recognize the relevance of mathematical knowledge in everyday life (Acharya et al., 2021; Kurniawan et al., 2023). Previous studies conducted in various educational settings have shown that ethnomathematics-based instruction improves learning motivation, conceptual understanding, and classroom engagement. The present findings reinforce these conclusions by demonstrating a substantial unmet need for culturally contextualized mathematics learning. Furthermore, the absence of cultural integration may contribute to students' perception that mathematics is disconnected from real-world experiences. This perception has been identified as a factor contributing to reduced interest and lower academic achievement in mathematics. Integrating ethnomathematical elements into AR Flip Cards therefore represents more than a motivational strategy; it serves as a pedagogical mechanism for bridging the gap between formal mathematical concepts and students' lived experiences. Such integration is expected to strengthen conceptual retention while simultaneously fostering cultural appreciation and identity development.

The effect size analysis provides additional support for the selection of ethnomathematics-based AR Flip Cards as the most appropriate instructional intervention. The superior effect size of Idea 1 (ES = 1.07) compared with gamification alone (ES = 0.91) and differentiated instruction (ES = 0.87) suggests that combining multiple evidence-based components yields greater educational benefits. This finding is consistent with multimedia learning theory, which posits that learning outcomes improve when information is presented through multiple complementary representations. The AR component specifically addresses students' difficulties in visualizing abstract mathematical concepts by providing interactive and concrete representations. Previous studies have reported that AR-enhanced mathematics learning significantly improves conceptual understanding and spatial reasoning. Meanwhile, the inclusion of Quizizz-based activities contributes opportunities for repeated practice, immediate feedback, and increased learner engagement. Research on digital formative assessment has demonstrated that timely feedback plays a critical role in developing students' problem-solving abilities. The ethnomathematics component further strengthens the intervention by situating mathematical content within meaningful cultural contexts. Compared with single-component interventions, integrated instructional designs are generally more successful because they simultaneously address cognitive, affective, and contextual dimensions of learning. Therefore, the higher effect size observed in this study reflects the synergistic impact of combining AR visualization, ethnomathematical contextualization, and structured digital practice within a unified learning framework.

Another important aspect of the proposed intervention is the integration of Problem-Based Learning (PBL) as the instructional model supporting the use of AR Flip Cards. PBL encourages students to investigate authentic problems, evaluate alternative solutions, and engage in reflective reasoning throughout the learning process. This characteristic directly addresses the tendency of students to bypass problem analysis and focus exclusively on formula application. Previous studies have consistently shown that PBL improves mathematical reasoning, critical thinking, and problem-solving performance across different educational levels. When combined with AR technology, PBL can further enhance learning by enabling students to interact with visual representations while exploring mathematical problems. The incorporation of ethnomathematical contexts adds an additional layer of authenticity by connecting problem situations to students' cultural environments. This combination aligns with contemporary constructivist perspectives, which emphasize active knowledge construction through meaningful experiences. The findings of this study therefore suggest that effective mathematics instruction should not rely on isolated pedagogical innovations but rather on integrated learning ecosystems that address multiple dimensions of student learning simultaneously. By combining ethnomathematics, augmented reality, flip card media, digital formative assessment, and problem-based learning, the proposed intervention creates a comprehensive framework for strengthening mathematical problem-solving skills. Ultimately, the results contribute to the growing body of evidence supporting culturally responsive and technology-enhanced mathematics education as a promising pathway for improving students' mathematical competencies in the twenty-first century.

Implications

The findings of this study have important implications for mathematics education theory, instructional practice, and educational policy. First, the identification of students' tendency to prioritize formula application over problem analysis suggests that mathematics instruction should shift from procedural-oriented approaches toward learning environments that explicitly cultivate analytical reasoning and problem-solving processes. Second, the substantial gap between students' learning needs and existing classroom practices highlights the necessity of designing instructional interventions that simultaneously address cognitive, affective, and contextual dimensions of learning. Third, the results provide empirical support for the integration of ethnomathematics as a means of contextualizing mathematical concepts within students' cultural experiences, thereby enhancing the relevance and meaningfulness of mathematics learning. Fourth, the high proportion of students who reported limited exposure to culturally connected mathematics instruction indicates that local cultural resources remain underutilized and should be systematically incorporated into curriculum implementation. Fifth, the superior effect size associated with the ethnomathematics-based Augmented Reality Flip Cards demonstrates that combining multiple evidence-based components can generate stronger learning outcomes than implementing isolated instructional innovations. Sixth, the findings suggest that Augmented Reality technology can serve as an effective tool for reducing conceptual abstraction by providing interactive visualizations that facilitate students' understanding of mathematical relationships. Seventh, the incorporation of digital formative assessment elements, such as structured quizzes and immediate feedback, may further strengthen students' engagement and self-regulated learning behaviors. Eighth, the integration of Problem-Based Learning within the proposed instructional design highlights the importance of creating opportunities for students to actively investigate, discuss, and solve authentic mathematical problems rather than merely reproducing procedural solutions. Ninth, from a teacher development perspective, the study underscores the need for professional training programs that equip teachers with the competencies required to integrate emerging technologies and culturally responsive pedagogies into mathematics instruction. Tenth, educational institutions should provide greater access to technological infrastructure and instructional resources that enable teachers to implement innovative learning strategies effectively. Eleventh, curriculum developers may consider embedding ethnomathematical content and technology-enhanced learning experiences within formal mathematics curricula to support the development of twenty-first-century competencies. Finally, the study contributes to the growing body of evidence suggesting that culturally grounded and technology-mediated instructional approaches offer a promising pathway for improving mathematical problem-solving skills while simultaneously fostering student engagement, cultural awareness, and meaningful learning experiences.

Limitations and Suggestions for Future Research

This study has several limitations that should be considered when interpreting the findings. First, the needs analysis was conducted within a limited geographical context, namely junior high schools in Batang Regency, which may restrict the generalizability of the results to other educational settings with different demographic, cultural, and institutional characteristics. Second, the study primarily relied on self-reported data collected from students and teachers, making the findings susceptible to response bias and subjective perceptions. Third, although the study identified the most promising instructional solution through effect size synthesis and needs assessment, it did not include the actual development, implementation, and experimental evaluation of the ethnomathematics-based Augmented Reality Flip Cards. Consequently, the effectiveness of the proposed intervention remains theoretical and requires empirical validation through classroom-based experimentation. Fourth, the effect size comparison was derived from previous studies conducted in different contexts, populations, and instructional conditions, which may introduce variability in the interpretation of comparative effectiveness. Fifth, the study focused predominantly on mathematical problem-solving skills and did not examine other potentially relevant outcomes such as mathematical creativity, critical thinking, learning motivation, self-efficacy, or mathematics anxiety. Sixth, the perspectives of school administrators, curriculum developers, and parents were not included, limiting the comprehensiveness of stakeholder analysis. Future research should therefore prioritize the design, development, and validation of ethnomathematics-based Augmented Reality Flip Cards through rigorous research and development frameworks. Subsequent studies are also encouraged to employ quasi-experimental or experimental designs involving larger and more diverse samples to evaluate the intervention's impact on mathematical problem-solving performance. In addition, longitudinal studies are needed to investigate the sustainability of learning gains and the long-term effects of culturally responsive technology-enhanced instruction. Future researchers may further explore the integration of additional pedagogical approaches, such as collaborative learning, adaptive learning systems, or artificial intelligence-supported feedback mechanisms, within the AR Flip Card environment. Finally, comparative studies across different regions, educational levels, and cultural contexts would provide deeper insights into the scalability, adaptability, and broader educational value of ethnomathematics-based Augmented Reality learning interventions.

CONCLUSION

This study concludes that the mathematical problem-solving difficulties experienced by junior high school students in Batang Regency stem from a combination of cognitive, instructional, and contextual factors. The findings revealed that many students tend to prioritize formula application over problem analysis, indicating a predominance of procedural learning habits rather than analytical problem-solving practices. At the same time, mathematics instruction remains largely teacher-centered, despite teachers' recognition of the limitations of conventional teaching approaches. The study also identified a substantial disconnect between mathematics learning and students' cultural environments, as the majority of students reported having little or no experience with ethnomathematics-based instruction. These findings suggest that existing instructional practices have not fully addressed students' needs for meaningful, engaging, and contextually relevant learning experiences. Through an integrated analysis of student and teacher perspectives, the study highlights the importance of instructional solutions that simultaneously address conceptual understanding, learning engagement, and cultural relevance. The comparative effect size analysis further demonstrated that the ethnomathematics-based Augmented Reality Flip Cards supported by Problem-Based Learning and digital formative assessment represent the most promising instructional alternative among the evaluated options. The superiority of this approach can be attributed to its ability to combine interactive visualization, culturally meaningful contexts, structured feedback, and active problem-solving experiences within a single learning framework. By integrating these complementary components, the proposed intervention has the potential to reduce conceptual abstraction, increase student engagement, and strengthen mathematical problem-solving competencies. The findings contribute to the growing body of evidence supporting the value of culturally responsive and technology-enhanced mathematics education in addressing persistent learning challenges. Furthermore, the study provides a practical and theoretically grounded foundation for the future development and implementation of innovative mathematics learning media that align with the demands of twenty-first-century education. Ultimately, ethnomathematics-based Augmented Reality Flip Cards offer a promising pathway for transforming mathematics instruction into a more meaningful, engaging, and effective learning experience for junior high school students.

AUTHOR CONTRIBUTIONS STATEMENT

Zakiyatul Miskiyyah contributed to conceptualization, data collection, investigation, formal analysis, data curation, visualization, and preparation of the original manuscript draft. Lukman Harun contributed to conceptualization, methodology development, supervision, validation, interpretation of findings, critical review and editing of the manuscript, and project administration. Muhtarom contributed to methodology refinement, validation, formal analysis, supervision, and manuscript review. All authors participated in the interpretation of the results, contributed substantially to the development of the manuscript, reviewed and approved the final version, and agreed to be accountable for all aspects of the work.

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