

Hy MAI: An ethno-STEM-based interactive website to improve high school students' reasoning skills

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Abstract

Prior studies on students' mathematical reasoning abilities have shown that multimodal representations and local culture can bridge the gap between abstract concepts and students' understanding. To address this gap, this study developed and evaluated the interactive website Hy MAI, grounded in the Ethno-STEM approach, as a pedagogical innovation and theoretical contribution to design-based mathematics education. This study used Research and Development methods within an educational design research framework. Participants included expert validators ($n = 4$), one mathematics teacher, and eleventh-grade students ($n = 74$; 37 experimental, 37 control). Data were collected through expert validation sheets, teacher and student questionnaires, and pre- and post-tests. Expert validation yielded an average score of 3.40 (Good), confirming the accuracy of the content, interactivity, and cultural integration. Teachers rated practicality at 4.00 (Very Good), while students rated it at 3.03 (Practical). Effectiveness analysis showed significant improvements in reasoning skills. A paired-sample t-test yielded $t(36) = -19.60$, $p < 0.001$, and an independent-sample t-test revealed a significant post-test difference, $t(72) = 8.77$, $p < 0.001$. The N-Gain analysis showed 62.35% for the experimental group versus 16.08% for the control group. Overall, Hy MAI proved valid, practical, and effective, while also making theoretical contributions by demonstrating the systematic integration of technology, STEM principles, and local culture in mathematics education.

Keywords:

Digital learning, Ethnomathematics, Interactive website, Mathematical reasoning, STEM approach

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1. INTRODUCTION

Mathematics plays a strategic role as an essential discipline in daily life and in various fields of science. One of the important competencies in mathematics education is mathematical

reasoning, which enables students to think logically, connect concepts, and solve problems systematically (Darta & Saputra, 2018; Simanjuntak et al., 2019; Sukirwan et al., 2018). Nevertheless, recent studies continue to show that Indonesian high school students' mathematical reasoning remains relatively low, particularly in the contexts of algebraic problem solving and geometric reasoning (Ayuningtyas et al., 2019; Nurtamam et al., 2024; Oemanas et al., 2024; Sunawan & Rosjanuardi, 2019; Teoh et al., 2025). These topics demand abstract thinking, symbolic representation, and conceptual connections, which makes them critical areas for examining students' reasoning skills. This weakness stems not only from conventional instruction that neglects critical thinking (Permatasari et al., 2025; Trisnani et al., 2024), but also from the lack of digital innovation and cultural contextualization. Without interactive technology and local cultural contexts, students struggle to connect abstract concepts with real-life experiences (Nicol et al., 2023; Rosa & Orey, 2021).

Given these challenges, innovative approaches are needed to strengthen students' reasoning and higher-order thinking. Digital technology has been widely recognized as a promising solution in mathematics education, particularly through interactive platforms that provide adaptive, personalized, and effective learning experiences. Among various digital tools, GeoGebra and AI-based chatbots are especially relevant when integrated into a single learning system: GeoGebra enables interactive visualization and exploration of mathematical concepts (Asyura & Dewi, 2020), while AI chatbots provide adaptive guidance and responsive feedback (Gökçe & Güner, 2022). Together, they foster deeper reasoning through visual exploration and dialogic scaffolding. In addition, chatbots contribute to accountability by documenting learning processes, while teachers remain central in interpreting records, ensuring ethical use, and aligning feedback with instructional goals. They also stimulate creativity by encouraging students to explore multiple strategies, pose questions, and engage in divergent thinking beyond routine procedures. Prior studies confirm that GeoGebra enhances visual reasoning (Gurmu et al., 2024; Yerizon et al., 2023; Zainudin et al., 2025) and that AI chatbots contribute to creative and interactive mathematics learning (Lee & Yeo, 2022; Son et al., 2024). AI chatbots foster creativity by encouraging students to generate multiple solution strategies, pose exploratory questions, and engage in dialogic problem solving that goes beyond routine procedures. Through adaptive prompts and responsive feedback, chatbots stimulate divergent thinking and help students connect mathematical concepts in novel ways, thereby supporting creative reasoning in mathematics. However, despite these advances, their integration with culturally contextualized approaches remains limited, which highlights the need to connect digital innovation with students' cultural identities.

Culturally responsive approaches, such as the Ethno-STEM framework, integrate STEM with local values to make learning meaningful (Matindike & Ramdhany, 2025; Nicol et al., 2023). Furthermore, the ethnomathematics perspective has been framed as a form of 'glocal' education, enhancing local relevance while preserving global STEM dimensions (Rosa & Orey, 2021). Studies demonstrate that ethnomathematics can enhance students' motivation, reasoning, and higher order thinking by connecting mathematical concepts to everyday life (Asyura et al., 2023; Nursyahidah et al., 2025; Wiryanto et al., 2022). For instance, in Pandeglang, cultural elements such as traditional music (e.g., Rebana), iconic architecture (e.g., Banten Grand Mosque), and culinary heritage (e.g., Emping crackers) can

serve as meaningful contexts for mathematics learning through culturally based reasoning problems. Bibliometric studies confirm that digital–Ethno-STEM integration remains weak (Deda et al., 2024; Komaladewi et al., 2024; Lakapu et al., 2025; Sumarni & Mauladaniyati, 2025), creating a clear gap and an opportunity for innovation.

To fill this gap, the design of Hy MAI is grounded in constructivist theory, which emphasizes active knowledge construction, and sociocultural theory, which highlights cultural context and dialogic interaction. These foundations guide the integration of STEM principles, ethnomathematics, and digital technologies to provide culturally meaningful and technologically adaptive learning. Building on these theoretical foundations, Hy MAI is positioned as a hybrid innovation that unites GeoGebra visualization, AI chatbot scaffolding, and ethnomathematical contextualization into a coherent learning system. Within this framework, the study focuses on the circle topic (arcs, tangents, and chords) as a representative geometry context aligned with high school competencies.

Accordingly, this study introduces Hy Mathematics Artificial Intelligence (Hy MAI), an Ethno-STEM–based interactive website designed to enhance high school students’ mathematical reasoning by integrating local culture with digital learning. This study aims to develop and evaluate Hy MAI in terms of its validity, practicality, and effectiveness. The research question guiding this study is: How valid, practical, and effective is the Hy MAI interactive website in improving students’ mathematical reasoning? By embedding local wisdom within interactive visual–verbal representations, this study offers a practical model for culturally grounded and technologically adaptive mathematics learning.

2. METHOD

This study employed the Research and Development (R&D) method by adapting the educational design research framework (Akker et al., 2006; Nieveen & Folmer, 2013). Educational design research is recognized as a systematic and iterative approach that enables the development of learning products which are valid, practical, and effective (Akker et al., 2006; Nieveen & Folmer, 2013). In this study, the development process followed the three main stages outlined by Nieveen and Folmer (2013), namely: preliminary research, prototyping, and assessment. The subsequent section provides a structured overview of the research process, with each stage of Hy MAI’s development described in terms of its main activities, instruments employed, and data analysis approaches, as summarized in Table 1.

Table 1. Research stages, instruments, and data analysis of Hy MAI

Stage	Main Activities	Instruments	Data Analysis
Preliminary research	Curriculum analysis. Student characteristics analysis. Exploration of local culture. Review of digital technologies (GeoGebra, AI chatbot).	Curriculum documents. Interviews. Cultural observations. Technology review.	Qualitative descriptive analysis (needs mapping, cultural context, technology readiness)

Stage	Main Activities	Instruments	Data Analysis
Prototyping phase	Apriori analysis (constructivist learning theory, Ethno-STEM studies, digital media research). Aposteriori analysis (iterative evaluations).	Self-evaluation. Expert review. One-to-one and small-group trials	Qualitative thematic analysis.
Assessment phase	Field test with 74 eleventh-grade students (control & experimental groups). Expert validation. Teacher and student questionnaires. Pretest–posttest instruments.	Expert validation sheets. Teacher & student questionnaires. Pretest–posttest reasoning tests.	Validity: Aiken’s V. Practicality & acceptability: qualitative and quantitative descriptive analysis. Effectiveness: descriptive statistics, independent sample t-test, dependent sample t-test, and N-Gain analysis. Descriptive statistics summarize students’ scores; independent sample t-tests examine differences between experimental and control groups; dependent sample t-tests assess pre-test and post-test differences within the same group; N-Gain analysis evaluates the magnitude of improvement in mathematical reasoning.

As summarized in [Table 1](#), each stage of Hy MAI’s development involved specific activities, instruments, and data analysis techniques. To provide greater transparency regarding the instruments employed, [Table 2](#) presents the development and validation procedures for the expert validation sheet, teacher and student questionnaires, and the pretest–posttest reasoning test.

Table 2. Instrument development and validation of Hy MAI

Stage	Main Activities	Data Analysis
Expert validation sheet	Constructed based on content validity criteria aligned with mathematics education standards; reviewed by four subject-matter experts	Validity measured using Aiken’s V to confirm item relevance
Teacher & student questionnaires	Adapted from previously established instruments; refined through limited pilot testing to ensure clarity and consistency of items	Reliability tested using Cronbach’s alpha; face validity confirmed through expert judgment
Pretest–posttest reasoning test	Designed according to national curriculum indicators in the topic of circle geometry; items reviewed by mathematics education experts prior to implementation	Validity confirmed through expert review; reliability tested using Cronbach’s alpha; empirical testing conducted with a pilot group before use

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Preliminary research stage

The preliminary research stage aims to identify the needs for developing an interactive Ethno-STEM-based learning medium (Hy MAI). The analysis was conducted from four key aspects: curriculum, student characteristics, local culture and wisdom, and relevant technology and learning media. This study integrates all STEM dimensions into Hy MAI: science through contextual analogies, technology via interactive simulations, engineering through simple model construction, and mathematics through problem solving. For example, in the circle–tangent subtopic, students relate light touching a curved surface (Science), use website simulations (Technology), build a cardboard dome model (Engineering), and calculate tangent lengths while proving congruence (Mathematics). Thus, all STEM components are represented, with stronger emphasis on technology and mathematics.

The Merdeka Curriculum highlights the importance of contextual, collaborative learning that fosters mathematical reasoning. This requires learning media that not only present abstract concepts but also connect them to daily life and local culture, since abstract mathematics is often difficult to grasp without contextual examples. Integrating ethnomathematics provides meaningful entry points for reasoning and application, bridging the national curriculum with students’ needs to understand abstract concepts (Payadnya et al., 2024). Curriculum-based needs analysis, through document review and teacher interviews, confirms the relevance of Hy MAI to the Merdeka Curriculum and high school mathematics competencies, particularly in circle-related topics (arcs, tangents, and chords). To reinforce these findings, a mapping was conducted between the Learning Objectives (LO), identified needs, and Hy MAI’s implementation features, as presented in Table 3.

Table 3. Relationship between merdeka curriculum learning objectives, identified needs, and Hy MAI implementation

Learning Objectives (LO)	Identified Needs	Implementation in Hy MAI
Understand the relationship of inscribed angles subtending the same arc	Dynamic visualization to concretely understand angle patterns	Interactive simulation of inscribed angles
Understand the relationship between central and inscribed angles	Linking geometric concepts with real objects	Visualization of mosque tower architecture
Apply circle theorems in problem solving	Contextual problems relevant to daily life	Practice problems based on food patterns
Prove theorems of central and inscribed angles	Exploratory media to support independent proof	GeoGebra exploration for independent proof
Discover properties of tangent lines to circles	Animation and real examples to understand tangents	Tangent line animation
Understand the relationship between chords and arc measures	Visual and manipulative approaches	Interactive exploration

Learning Objectives (LO)	Identified Needs	Implementation in Hy MAI
Prove theorems related to chords	Step-by-step interactive activities	Point manipulation based on motifs
Explore cyclic quadrilaterals	Reasoning problems based on cultural contexts	Contextual cases

High school students, in Piaget’s formal operational stage, can reason abstractly and use deductive logic (Cerovac & Keane, 2025). Yet, they often need visual and contextual support to understand abstract mathematics. Visual models and contextual problem-solving help bridge this gap (Mainali, 2020; Pujilestari & Juliangkary, 2025), while multimodal and culture-based visualizations reduce cognitive load and improve problem-solving (Anwar et al., 2025; Ruamba et al., 2025). Interactive digital media with animations and cultural illustrations further enhance motivation and conceptual understanding (Kabuye Batiibwe, 2024).

Table 1 maps Merdeka Curriculum objectives to student learning needs, Hy MAI implementation, and local cultural artifacts. This mapping shows how abstract circle concepts are grounded in interactive media and cultural contexts. For example, rebana and bedug illustrate inscribed and central angles, while ali cake serves as a cultural and visual analogy for circle concepts through its ring-shaped form. These contextual examples act as entry points that encourage students to connect everyday cultural artifacts with formal mathematical ideas. The integration of Banten’s local culture into circle topics was guided by curriculum review and teacher input. Cultural artifacts—rebana, ali cake, bedug, and batik motifs—anchor circle concepts, such as inscribed and central angles (rebana, bedug) and circle theorems (ali cake). As shown in Table 3, these familiar elements provide accessible entry points, enhancing understanding and fostering cultural pride (Payadnya et al., 2024; Pujilestari & Juliangkary, 2025). This reflects the Ethno-STEM approach, which connects STEM with local values to strengthen engagement and empowerment (Anwar et al., 2025; Ruamba et al., 2025).

Students’ digital literacy further supports the use of web-based media. Regular device use enables access to interactive platforms that combine STEM and ethnomathematics through simulations and practice activities. Studies confirm that such platforms increase engagement and promote higher-order thinking (Selano et al., 2024). Thus, web-based interactive media provide a feasible and effective foundation for developing the Hy MAI platform.

3.1.2. Prototyping stage

The prototyping stage ensured Hy MAI’s alignment with curriculum, learner needs, and Banten’s culture. Circle material was contextualized with rebana, bedug, and ali cake, supported by UI/UX design, animations, and interactive features. Continuous evaluation improved clarity and navigation, producing a feasible prototype published at www.hymai.id. The main menu (see Figure 1) introduces the theme “Understanding Ethno-STEM: A Bridge Between Science and Culture” and offers two options: Material & Cultural Exploration and Reasoning Test.

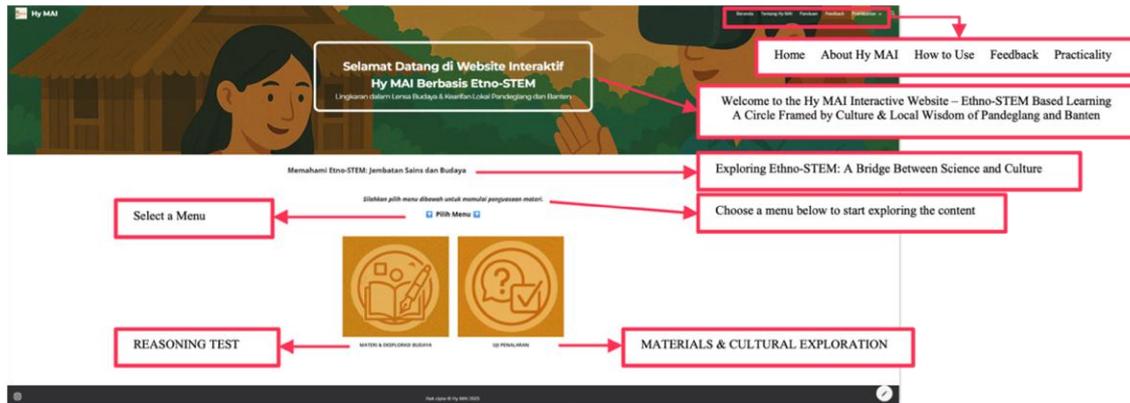


Figure 1. Hy MAI main menu

The cultural and mathematics exploration menu (see Figure 2) integrates Pandeglang and Banten’s local culture into circle learning. Icons such as rebana and bedug are used because of their circular frames, the Banten Grand Mosque is highlighted through its dome structure, and tutup saung is represented by its round cover shape. These cultural artifacts provide contextual entry points to circle-related mathematical content. The design makes learning concrete and meaningful, while the Ethno-STEM reflection feature links cultural aesthetics with mathematical reasoning.

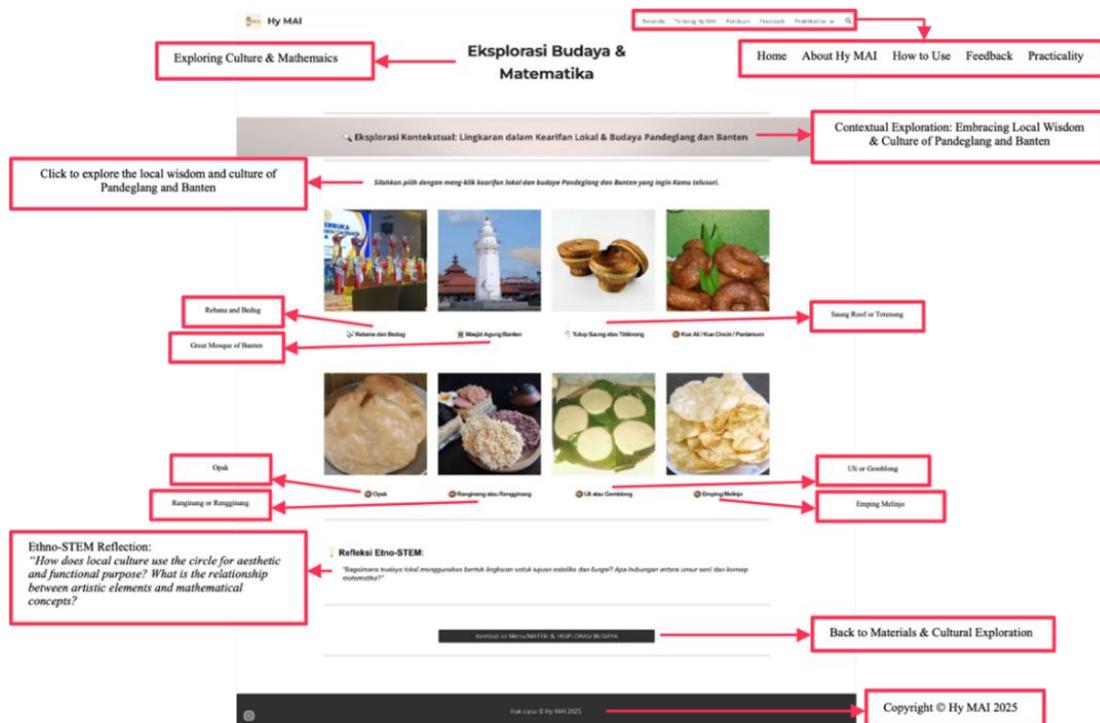


Figure 2. Cultural and mathematical exploration menu

Hy MAI circle learning for grade XI covers arcs, tangents, and chords. Local culture from Pandeglang and Banten—such as rebana, bedug, mosque domes, rengginang, and emping—serves as contextual anchors (see Figure 3). This ethnomathematics approach connects abstract circle concepts with students’ real-life experiences.

Hy MAI

Home About Hy MAI How to Use Feedback

STRUKTUR UMUM MATERI

Main Theme : Circle (Grade XI Senior High School)
 Approach : Ethno-STEM + Project-Based Learning
 Local Cultural Context : Pandeglang and Banten

General Structure of the Material

Division of Subtopics
 Please select a menu by clicking the subtopic you would like to study first.

1. Circle and Arc of a Circle Concepts

- Central angle
- Inscribed angle
- Relationship between central angle and inscribed angle

Related Cultural Objects

- Rebana (traditional drum)
- Bedug (large drum used in mosques)
- Water Tower (cylindrical structure with circular base)
- Ali Cake / Ring Cake (traditional circular-shaped snack)

Project-Based Learning Activity

- Observe cultural objects (e.g., rebana and bedug), measure angles, and discover the relationship between the central angle and the inscribed angle.

2. Circle and Tangent Line Concepts

- Tangent line to a circle from a point outside the circle
- Length of the tangent line
- Relationship between radius and tangent line

Related Cultural Objects

- Great Mosque of Banten (dome roof → tangent lines can be drawn)
- Saung Roof (Téténgong bamboo weaving)

Project-Based Learning Activity

- Simulate drawing a tangent line from a point outside a cultural object (e.g., mosque dome or saung roof), experiment with the length of the tangent line, and draw conclusions about the relationship between the radius and the tangent.

3. Circle and Chord Concepts

- Chord of a circle
- Distance from the center to the chord
- Cyclic quadrilateral (quadrilateral formed by chords of a circle)

Related Cultural Objects

- Rengginang (traditional rice cracker), Emping (melinjo cracker), Ali Cake / Ring Cake (circular-shaped snack)
- These foods can be used to simulate circle segments and chords by cutting or marking circular portions.

Project-Based Learning Activity

- Observe "rengginang slices" or decorative patterns in emping. Students draw and measure chords, then discover the properties of cyclic quadrilaterals formed within the circle.

Back to MATERIALS & CULTURAL EXPLORATION

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Figure 3. Sub-material menu

Hy MAI’s Material & Practice connects circle concepts with cultural artifacts (rebana, bedug) through simulations, STEM projects, and GeoGebra to foster reasoning and creativity. The section concludes with Self-Reflection and “Mathematics is All Around You!”. In the Rebana Model activity, GeoGebra applies Kolb’s cycle as students prove central–inscribed angle relationships and simulate tangent constructions, strengthening problem formulation and evidence-based reasoning (see Figure 4).



Figure 4. One of the material simulation displays

A summary of the mathematical reasoning ability indicators in the Hy MAI activities is presented in Table 4.

Table 4. Correlation of mathematical reasoning indicators with Hy MAI-assisted Ethno-STEM

Mathematical Reasoning Indicators	Hy MAI-assisted learning activity (Ethno-STEM + PjBL)	Student Achievement Form	Documentation
Conjecturing	Observing the shape of the <i>rebana</i> and <i>bedug</i> to connect the concepts of circles with central angles and inscribed angles.	Students form an initial conjecture that the measure of an inscribed angle is always half of the central angle subtending the same arc.	

Mathematical Reasoning Indicators	Hy MAI-assisted learning activity (Ethno-STEM + PjBL)	Student Achievement Form	Documentation
Reasoning	Completing a project to draw a tangent line to a circle from an external point.	Students logically explain why the lengths of two tangent lines from an external point to a circle are always equal.	
Drawing conclusion	Exploring circle patterns on <i>rengginang</i> and <i>emping</i> in relation to symmetry and repetition of shapes.	Students conclude that there is a mathematical regularity in the local cultural patterns.	
Verifying	Performing a simple proof through Hy MAI about the relationship between central and inscribed angles using an interactive simulation.	Students verify the conjecture with visual evidence and mathematical calculations.	
Connecting	Reinforcing circle concepts by linking them with cultural phenomena (mosque towers, bedug, rebana) and extending them through Hy MAI digital simulation.	Students exhibit an understanding that the concept of circles is interconnected with real-life contexts and applications across STEM fields.	

Table 4 shows that each mathematical reasoning indicator can be facilitated through project-based activities on Hy MAI. Thus, the integration of Ethno-STEM not only provides a cultural context but also provides a space for students to build arguments, conduct proofs, and draw valid mathematical conclusions.

The About Hy MAI menu features an AI-based chatbot that serves as a virtual assistant, providing access to supplementary Ethno-STEM and mathematics resources. When students encounter key terms during learning (e.g., mathematical reasoning, Ethno-STEM, algorithm), the chatbot provides concise and contextual explanations to support their understanding. This feature is designed as a support tool to enhance practicality, helping students clarify concepts without leaving the platform, rather than introducing unfamiliar terms.

The homepage features a digital brain illustration symbolizing artificial intelligence and an interactive window for the Hy MAI Virtual Assistant. A navigation menu at the top includes the prompt: “Please utilize the Virtual Assistant to explore Hy MAI, Ethno-STEM, and Mathematics.” On the right, a pop-up chatbot greets users with “Hi, Hy MAI friend 🙌”

How can I help you?” and displays a conversation history (e.g., “Explain Hy MAI to me?”). A message field at the bottom allows users to interact directly with the assistant.

Theoretically, the chatbot aligns with principles of scaffolding, self-regulated learning, assessment for learning, social presence, and cognitive load reduction. Importantly, scaffolding is not left entirely to students’ independence; the chatbot provides adaptive support when learners encounter difficulties, ensuring that guidance remains available. Empirical evidence confirms that educational chatbots positively influence student performance and experience. Meta-analyses and systematic reviews (2021–2024) report small-to-medium effects on learning achievement and highlight benefits for personalization for both students and teachers (Kuhail et al., 2023; Labadze et al., 2023).

Beyond providing explanations, the chatbot’s adaptive feedback mechanisms encouraged students to articulate their reasoning processes, reflect on errors, and refine their problem-solving approaches. Student perceptions highlighted the chatbot as an interactive partner that supported reasoning development, rather than a passive source of information.

Validity of the product

Expert validation was conducted to assess the feasibility of the Ethno-STEM-based Hy MAI interactive website before the field test stage. The aspects validated included: (1) mathematical content or material, (2) evaluation or assessment, (3) learning or interactive media, (4) local culture and Ethno-STEM integration, and (5) general feasibility (display, navigation, and other technical aspects).

Quantitative results indicated that the Hy MAI website achieved an overall average score of 3.40, categorized as “Good,” thereby confirming its feasibility with minor revisions. The highest score was obtained in the aspect of local culture and Ethno-STEM integration (3.59, Good), which validated the successful contextualization of mathematical content through cultural artifacts. General feasibility also received a high rating (3.50, Good), reflecting the appropriateness of interface design and navigation. In contrast, the lowest score was recorded in the learning media aspect (3.17, Sufficient), suggesting the need for improvement in interactivity, accessibility, and responsiveness to student characteristics. Mathematical content was rated 3.30 (Sufficient), indicating that further refinement was required to strengthen clarity, systematic structure, and curriculum alignment.

Validator feedback highlighted strengths and weaknesses of the product. Experts advised simplifying page layouts, reinforcing links between circle concepts and cultural artifacts like rebana, bedug, and ali cake, embedding authentic images and videos in GeoGebra, and improving navigation. Based on these insights, the prototype was revised for clarity, cultural contextualization, and smoother interactivity. The final Hy MAI website met feasibility criteria while aligning with curriculum, integrating local culture, and ensuring technological accessibility.

Practicality of the product

The practicality evaluation of the Ethno-STEM-based Hy MAI website showed positive results. Teachers rated it Good–Very Good (average 4.00) across indicators of usefulness, engagement, cultural integration, navigation, and sustainability. They noted that

Hy MAI supports circle learning, increases student participation, aligns with project-based learning, and effectively integrates Banten's local culture (rebana, ali cake, bedug) to strengthen understanding and reasoning. Overall, teachers found Hy MAI easy to use, beneficial, and feasible for wider implementation, fulfilling the functionality criteria of educational products (Akker et al., 2013).

Following the teachers' evaluation, which confirmed the practicality of Hy MAI, the next assessment focused on students' perspectives. The student practicality test yielded an overall average score of 3.03, categorized as "Practical." The highest ratings reflected students' pride in learning mathematics through their own culture (3.19) and their appreciation of visual displays and animations such as rebana and ali cake (3.16). These findings highlight that the integration of Banten's local culture in Hy MAI provides emotional appeal and enhances learning motivation. Students also valued the ability to connect circle principles with cultural elements (3.11) and found project-based learning activities enjoyable (3.11).

Some areas of Hy MAI need improvement. Students gave lower scores for understanding circle concepts (2.78) and navigation (2.81), both "Sufficiently Practical," and showed modest interest in using it for other topics (2.97). This suggests the need for richer interactive features and better navigation. Overall, Hy MAI was considered practical, but feedback highlights the importance of strengthening conceptual understanding and ensuring sustainable use. Comparative analysis shows teachers rated the website higher (4.00, Good) than students (3.03, Practical), with a 0.97 gap reflecting teachers' focus on functionality and teaching ease versus students' emphasis on usability (see Table 5).

Table 5. Comparison of Hy MAI practicality

Assessment Aspect	Teachers (average)	Teachers' Category	Students (average)	Students' Category	Perception Gap
Overall	4.00	Good	3.03	Practical	0.97

3.1.3. Assessment stage

Effectiveness of the product

The effectiveness test showed a marked improvement in students' mathematical reasoning with Hy MAI. The experimental group's average score increased from 6.16 (pre-test) to 14.76 (post-test), while the control group rose only from 7.62 to 8.72. This difference demonstrates that Hy MAI contributed to a full grade-level improvement, providing strong evidence of its positive impact on student learning (see Table 6).

Table 6. Results of descriptive analysis

Group	N	Minimum	Maximum	Mean	Std. Deviation
Pretest Experimental Group	37	3	11	6.16	2.267
Posttest Experimental Group	37	9	18	14.76	2.397
Pretest Control Group	37	2	13	7.62	2.701
Posttest Control Group	37	3	15	8.72	2.791

The N-Gain analysis confirmed Hy MAI’s effectiveness, with the experimental group achieving 62.35% (categorized as Sufficiently Effective according to Meltzer (2002), and still applied in recent studies, e.g., Triyono et al. (2024)) compared to 16.08% (Not Effective) in the control group. Furthermore, the independent samples t-test revealed highly significant differences in both N-Gain and post-test scores ($p < 0.05$). These inferential results provide robust statistical evidence that Hy MAI significantly improves students’ mathematical reasoning (see Table 7).

Table 7. N-Gain score test results

Group		Statistic	Std. Error
Experimental Group	Mean	62.3542	2.48649
	Std. Deviation	15.12474	
	Minimum	35.29	
	Maximum	87.50	
Control Group	Mean	16.0825	2.38285
	Std. Deviation	14.49432	
	Minimum	0.00	
	Maximum	66.67	

The paired-samples t-test in the experimental group revealed a significant difference between pretest and posttest scores ($t = -19.602$, $p < 0.05$). The average score increased by 8.405 points, confirming that Hy MAI made a substantial contribution to improving students’ mathematical reasoning skills, as presented in Table 8.

Table 8. Results of the paired-samples-T-Test for pretest-posttest scores of the experimental class

	Paired Differences							
	95% Confidence Interval of the Difference							
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pretest - Posttest Experimental	-8.405	2.608	.429	-9.275	-7.536	-19.602	36	.000

The Independent Samples T-Test revealed a significant difference between the experimental group using Hy MAI and the control group (see Table 9). With $t(72) = 8.774$, $p < 0.001$, and a mean difference of 5.216 points (95% CI [4.031, 6.401]), the null hypothesis (H_0 : there is no difference in post-test performance between groups) was rejected, and the alternative hypothesis (H_1 : students using Hy MAI achieve higher post-test performance than those in conventional learning) was accepted. These results confirm that Hy MAI has a substantial positive impact on students’ post-test performance compared to conventional learning.

Table 9. Independent-Samples T-Test Result for Posttest Scores (Experimental and Control Group)

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2- tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper	
Post- test Score	Equal variances assumed	1.828	.181	8.774	72	.000	5.216	.594	4.031	6.401
	Equal variances not assumed			8.774	69.455	.000	5.216	.594	4.030	6.402

This finding aligns with previous research, which highlights that ethnomathematics-based learning enhances reasoning skills by helping students connect abstract concepts with familiar local cultural practices (Kusuma et al., 2019; Kyeremeh et al., 2023). As an interactive digital medium, Hy MAI fosters active engagement through visualization, animation, and simulations, supporting findings that digital technology significantly improves reasoning skills (Gui et al., 2023; Sarioğlan & Özkaya, 2023). Integrating local culture—such as rebana, bedug, and ali cake—into circle concepts aligns with ethnomodelling theory (Rosa & Orey, 2013), bridging culture and STEM. Thus, Hy MAI is not only a digital innovation but also an effective pedagogical strategy to significantly improve students' mathematical reasoning.

3.2. Discussion

This study developed and implemented the Ethno-STEM-based Hy MAI interactive website to enhance mathematical reasoning. Validation confirmed its pedagogical soundness, technological relevance, and cultural significance, with experts rating it highly for mathematical content, cultural integration, and interactivity. By incorporating artifacts such as rebana, ali cake, and bedug, Hy MAI reflects ethnomathematics principles and supports findings that cultural contexts strengthen geometric understanding and identity Kusuma et al. (2019). Thus, Hy MAI meets national curriculum standards while adding value by reinforcing cultural identity in mathematics learning.

Second, the practicality assessment revealed a perception gap: teachers rated Hy MAI highly ($M = 4.00$, Good), emphasizing usefulness, while students rated it lower ($M = 3.03$, Practical), highlighting challenges in navigation (2.81) and conceptual clarity (2.78). This aligns with the Technology Acceptance Model (TAM), which distinguishes perceived usefulness from ease of use (Akbarini, 2024; Santini et al., 2025). Additionally, studies comparing digital learning technologies have found that tools with technical delays or unintuitive interfaces (e.g., mobile VR) significantly reduce student acceptance, despite their strong pedagogical potential (Sprenger & Schwaninger, 2021). This is relevant to Hy MAI's navigation, which requires enhancement.

Recommendations for Hy MAI's development include refining navigation, strengthening conceptual scaffolding, adding culturally aware gamification, evaluating with TAM, and conducting broader trials. The perception gap shows teachers value digital innovations more, while students emphasize usability. Effectiveness tests confirmed

significant gains in mathematical reasoning (medium–high N-Gain), supporting research that digital STEM learning enhances outcomes and higher-order thinking. Cultural integration through rebana, bedug, ali cake, and mosque towers aligns with ethnomathematics studies, showing that culture-based approaches strengthen understanding, motivation, identity, and critical thinking. Overall, Hy MAI provides international evidence that combining digital technology, STEM, and local culture enriches mathematics learning, with future research needed to test scalability, sustainability, and impact on teacher development and curriculum innovation.

In addition, the AI-based chatbot embedded in Hy MAI contributed to reasoning development by providing adaptive feedback, prompting students to articulate their thought processes, and guiding them to refine problem-solving approaches. Student perceptions indicated that the chatbot was valued as an interactive partner that supported reasoning, rather than a passive source of information.

4. CONCLUSION

This study addressed the low mathematical reasoning skills of students in conventional learning without digital media or cultural contexts. The Ethno-STEM-based Hy MAI interactive website was proven valid, practical, and effective in improving reasoning abilities. Expert validation confirmed its quality in content, language, presentation, and graphics, while teacher and student assessments showed it is user-friendly and aligned with learning needs. The learning effectiveness was confirmed through paired and independent t-tests, as well as N-Gain analysis. The N-Gain results were not only presented descriptively but also reinforced by inferential testing. The independent samples t-test revealed significant differences between the experimental and control groups ($p < 0.05$). This inferential evidence strongly confirms that Hy MAI significantly enhances students' mathematical reasoning abilities compared to conventional learning. These results confirm that Hy MAI enhances mathematical reasoning and demonstrates how digital technology, STEM, and local culture can produce innovative and relevant learning tools.

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Declarations

Author Contribution : IA: Conceptualization, Data curation, Formal analysis, Methodology, Software, and Writing - original draft; ASP: Investigation, Project administration, and Resources; L: Formal analysis, Investigation and Resources; BM: Resources, and Visualization; AI: Resources, and Software.

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