



Development and experimental validation of discovery learning-based worksheets integrating cultural context to enhance students' mathematical literacy and self-regulated learning

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Article Info

Article history:

Received: Feb 28, 2026
Revised: April 15, 2026
Accepted: May 03, 2026

Keywords:

Discovery Learning; Student Worksheets (LKPD); Mathematical Conceptual Understanding; Cultural Context; Mathematics Education.

Abstract

Background: Mathematics learning often relies on conventional teaching materials that are less effective in supporting students' conceptual understanding, particularly in abstract topics such as curved surface geometry. This limitation contributes to students' learning difficulties and low engagement, as instructional media rarely integrate meaningful cultural contexts that can connect mathematical concepts to students' real-life experiences.

Aims: This study aims to develop Discovery Learning-based student worksheets (LKPD) integrated with the Hadroh cultural context to enhance students' conceptual understanding in mathematics learning.

Method: This study employed a research and development design using the ADDIE model, which includes analysis, design, development, implementation, and evaluation stages. The participants were Grade IX students selected through purposive sampling. Data were collected using expert validation sheets, student response questionnaires, and conceptual understanding tests. Data analysis was conducted based on validity, practicality, and effectiveness criteria.

Results: The findings indicated that the developed LKPD achieved a high level of validity, with an average score of 4.39 categorized as very valid. The practicality test showed a percentage of 84%, indicating that the worksheets were highly practical for classroom use. Furthermore, the effectiveness test revealed that students who used the developed LKPD demonstrated better conceptual understanding compared to those who used conventional teaching materials.


Conclusion: The Discovery Learning-based LKPD integrated with the Hadroh cultural context is valid, practical, and effective in improving students' conceptual understanding, providing an alternative instructional material that supports more meaningful and student-centered mathematics learning.

To cite this article: Wijayanti, W., & Subekti, F. E. (2026). Development and experimental validation of discovery learning-based worksheets integrating cultural context to enhance students' mathematical literacy and self-regulated learning. *Journal of Advanced Sciences and Mathematics Education*, 6(2), 113-133.

INTRODUCTION

Mathematics learning in schools is often perceived as disconnected from students' real-life experiences, which reduces students' interest and engagement in learning. The abstract nature of mathematical concepts frequently leads to difficulties in understanding, especially when students are required to visualize and interpret complex ideas (Ayeh, 2025; Manfreda Kolar & Hodnik, 2021; Säfström et al., 2024; Verschaffel et al., 2020; Ye et al., 2023). As a result, many students demonstrate low levels of independent learning and limited participation in exploring mathematical concepts (Attard & Holmes, 2022; Bringula et al., 2021; Hafidzah et al., 2021; Lo & Hew, 2020; Susiani et al., 2022). This condition indicates that current instructional practices have not fully supported the development of meaningful learning experiences. In the context of 21st-century education, students are expected to possess critical thinking skills, creativity, and the ability to manage their own learning

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processes (Dilekçi & Karatay, 2023; Thornhill-Miller et al., 2023). These competencies are reflected in the development of self-regulated learning and mathematical literacy. However, such competencies cannot be achieved through conventional teaching approaches that focus primarily on knowledge transmission. Instead, learning should be designed to encourage active participation and deeper engagement. Students need opportunities to construct their own understanding through meaningful interactions and experiences. Therefore, improving mathematics learning requires a shift toward more student-centered and experience-based instructional approaches.

In line with these demands, learning is no longer viewed as a passive process but as an active construction of knowledge by students. This perspective emphasizes the importance of involving students in activities that allow them to explore, investigate, and discover concepts independently (Bhardwaj et al., 2025; Manz et al., 2020; Maroukias et al., 2023). One approach that aligns with this perspective is Discovery Learning, which encourages students to engage in a systematic process of inquiry (Brookes et al., 2020; Rodriguez et al., 2020; Sam, 2024). Through stages such as stimulation, problem identification, data collection, data processing, verification, and generalization, students are guided to construct their own understanding (Gizaw & Sota, 2023; Ristanto et al., 2022; Sreelohor et al., 2025). This process not only enhances conceptual comprehension but also develops students' ability to think critically and solve problems. Furthermore, Discovery Learning supports the development of self-regulated learning by encouraging students to plan, monitor, and evaluate their learning activities (Ahmad, 2024; Balazinec et al., 2024; Öztürk & Çakıroğlu, 2021; Yazdani & Sadeghi, 2022). Students become more responsible for their own learning and are better able to regulate their cognitive processes. As a result, learning becomes more meaningful and sustainable. However, the effectiveness of Discovery Learning depends on how well it is supported by appropriate instructional materials. Therefore, the development of instructional materials that align with Discovery Learning principles is essential.

In addition to pedagogical approaches, the integration of cultural context in mathematics learning is increasingly recognized as a strategy to enhance relevance and engagement. Cultural-based learning enables students to connect abstract mathematical concepts with familiar experiences from their daily lives. By incorporating elements of local culture, learning becomes more meaningful and easier to understand. In this context, traditional cultural practices can be used as representations of mathematical concepts (Acharya et al., 2021; Aprinastuti & Kovács, 2025; Fauzi et al., 2022; Lidinillah et al., 2022). For example, musical instruments can illustrate geometric shapes, patterns, and proportional relationships in a concrete manner. The use of cultural context not only facilitates conceptual understanding but also increases students' motivation and participation in learning (Anyichie & Butler, 2023; Hariyono et al., 2023; Xia et al., 2024). Moreover, it contributes to the preservation and appreciation of local cultural values within the educational process. One form of instructional media that can support this approach is the student worksheet, which provides structured guidance for learning activities. Student worksheets are designed to facilitate independent and systematic learning, allowing students to actively engage with the material. However, many existing worksheets are still procedural and do not fully support exploration or contextual learning.

Although previous studies have highlighted the importance of ethnomathematics in enhancing students' engagement and connecting mathematical concepts with cultural contexts, most of these works focus on conceptual perspectives, cross-cultural analyses, or general applications rather than embedding cultural elements into structured instructional materials such as student worksheets (Kabuye Batiibwe, 2024; Payadnya et al., 2024; Sari et al., 2023). At the same time, research on Discovery Learning has demonstrated its effectiveness in improving students' conceptual understanding and problem-solving skills through active and inquiry-based learning processes, yet these studies often examine pedagogical strategies in isolation without integrating culturally

relevant contexts (Mariyana et al., 2020; Purwaningsih et al., 2020; Yilmaz, 2020). Furthermore, studies on instructional materials and learning technologies emphasize their significant role in supporting conceptual understanding and shaping mathematical learning experiences, but they rarely incorporate both active learning approaches and cultural contextualization within a single design (Choppin et al., 2022; Kong et al., 2023). Consequently, despite the growing body of research in these areas, there remains a lack of empirical studies that integrate ethnomathematics, Discovery Learning, and instructional material development into a unified learning design. In particular, limited attention has been given to the development and validation of Discovery Learning-based worksheets that integrate specific cultural contexts to enhance students' conceptual understanding, especially in geometry learning, indicating a clear gap that warrants further investigation.

Based on the issues identified, this study aims to develop Discovery Learning-based student worksheets integrated with the cultural context of Hadroh musical instruments to enhance students' self-regulated learning and mathematical literacy. The study seeks to design instructional materials that support active exploration and meaningful learning experiences. In addition, this research aims to evaluate the quality of the developed worksheets in terms of validity, practicality, and effectiveness. The development process is conducted systematically to ensure that the resulting materials meet both academic and pedagogical standards. Furthermore, the study examines how the integration of cultural context can improve students' engagement and conceptual understanding. The effectiveness of the worksheets is assessed through their impact on students' learning outcomes. This research also aims to provide an alternative approach for developing instructional materials that are both contextual and student-centered. The findings are expected to contribute to the improvement of mathematics teaching practices. In addition, this study offers insights into how cultural elements can be integrated into modern educational approaches. Ultimately, this research aims to support the development of more meaningful, engaging, and effective mathematics learning.

LITERATURE REVIEW

Conceptual understanding is a fundamental objective in mathematics education because it enables students to grasp underlying principles rather than merely memorizing procedures. It involves the ability to connect mathematical ideas, interpret relationships, and apply concepts in various contexts (Baiduri et al., 2020; Manfreda Kolar & Hodnik, 2021). Students with strong conceptual understanding are better equipped to solve problems and transfer knowledge to new situations (Banda & Nzabahimana, 2021; Falloon, 2020; Ozkan & Umdu Topsakal, 2021). However, many students still struggle to achieve this level of understanding due to the abstract nature of mathematics. Traditional teaching approaches often emphasize algorithmic procedures, which can limit students' ability to develop deep comprehension (Al Ka'bi, 2023; Lehmann, 2024; Nijenhuis-Voogt et al., 2023). As a result, learning becomes superficial and disconnected from real-life applications. Effective mathematics instruction should therefore focus on developing conceptual understanding through meaningful learning experiences (Koskinen & Pitkäniemi, 2022; Ncube & Luneta, n.d.; Polman et al., 2021). This requires instructional strategies that engage students actively in the learning process. Providing opportunities for exploration and inquiry can help students construct their own understanding. Consequently, improving conceptual understanding remains a central concern in mathematics education research.

Discovery Learning is an instructional approach that emphasizes active student involvement in constructing knowledge through exploration and inquiry. This approach is grounded in the constructivist perspective, which views learning as an active process of meaning-making (Duran & Jones, 2020; Frödin, 2025; Li & Zhang, 2025; Matusov, 2020). In Discovery Learning, students are encouraged to identify problems, gather information, and derive conclusions independently

(Manurung & Pappachan, 2025; Ristanto et al., 2022). The structured stages of this approach guide students through a systematic learning process while allowing flexibility for exploration (Aljawarneh, 2020; A. Chen et al., 2026; Hung et al., 2020; Kim et al., 2025; Zydney et al., 2020). This method has been shown to improve students' engagement and promote deeper understanding of mathematical concepts (Attard & Holmes, 2020; Irvine, 2020; Lo & Hew, 2021). By participating actively in the learning process, students develop critical thinking and problem-solving skills. Discovery Learning also supports the development of independent learning behaviors. However, its effectiveness depends on the availability of well-designed instructional materials. Without proper guidance, students may experience confusion during the exploration process. Therefore, integrating Discovery Learning with appropriate learning materials is essential to maximize its effectiveness.

Self-regulated learning refers to students' ability to manage their own learning processes through planning, monitoring, and evaluation. It is an essential component of effective learning, particularly in mathematics where problem-solving requires persistence and strategic thinking. Students with strong self-regulated learning skills are more capable of setting goals and adapting their strategies when facing difficulties (García-Pérez et al., 2021; Ridgley et al., 2022; L. Wang, 2021). This ability contributes to improved academic performance and deeper understanding. In addition, mathematical literacy is another important competency that enables students to apply mathematical knowledge in real-life contexts (Bolstad, 2023; Manfreda Kolar & Hodnik, 2021). It involves interpreting, analyzing, and communicating mathematical information effectively. Mathematical literacy reflects the relevance of mathematics in everyday life and supports informed decision-making (Díez-Palomar et al., 2023; Ozkale & Ozdemir Erdogan, 2022; Reyna & Brainerd, 2023). The development of both self-regulated learning and mathematical literacy requires instructional approaches that are interactive and meaningful. Learning environments should encourage students to actively engage with problems and reflect on their learning processes. Therefore, integrating these competencies into mathematics instruction is crucial for preparing students for real-world challenges.

The integration of cultural context in mathematics education has gained increasing attention as a way to make learning more meaningful and relevant. Cultural-based learning, often associated with ethnomathematics, emphasizes the connection between mathematical concepts and cultural practices (Sunzuma & Umbara, 2025). This approach allows students to understand mathematics through familiar contexts, which can enhance comprehension and engagement. By incorporating cultural elements, abstract concepts become more concrete and easier to visualize. Cultural context also plays a role in increasing students' motivation and participation in learning activities (Anyichie & Butler, 2023; Bai et al., 2021; Kristiawan et al., 2022; M.-T. Wang et al., 2020). In addition, it supports the preservation and appreciation of local cultural values. Traditional cultural artifacts, such as musical instruments, can serve as effective representations of mathematical concepts (Kurniawan et al., 2023). These artifacts provide real-world examples that help students connect theory with practice. However, the application of cultural context in classroom materials is still limited. Therefore, further development is needed to integrate cultural elements systematically into instructional design.

Instructional materials play a crucial role in facilitating effective learning by providing structured guidance for students. Among various types of materials, student worksheets are widely used to support learning activities in the classroom. Worksheets are designed to guide students through tasks that promote understanding and skill development. They can be used to implement various instructional approaches, including Discovery Learning. Well-designed worksheets can encourage active participation and independent learning. They also help students organize their thinking and engage in systematic problem-solving processes. However, many existing worksheets are still limited to procedural exercises and do not support exploration. As a result, their contribution

to conceptual understanding remains suboptimal. To address this issue, worksheets should be designed to integrate active learning strategies and contextual elements. Combining Discovery Learning with cultural context in worksheet design has the potential to enhance learning outcomes.

METHOD

Research Design

This study employed a research and development (R&D) design with a quantitative approach aimed at developing and evaluating Discovery Learning-based student worksheets (LKPD) integrated with the Hadroh cultural context. The primary objective of this study was not only to produce an instructional product but also to examine its validity, practicality, and effectiveness in enhancing students' self-regulated learning and mathematical literacy. The quantitative approach was used to obtain numerical data that could be analyzed statistically, ensuring that the developed product was empirically tested in real learning settings through both limited trials and field trials. The development process followed the ADDIE model, which consists of five systematic stages: analysis, design, development, implementation, and evaluation. This model was selected because of its structured and iterative nature, allowing continuous revision and improvement at each stage. In addition, the ADDIE model provides a comprehensive framework to ensure that the developed instructional materials meet both pedagogical and practical requirements.

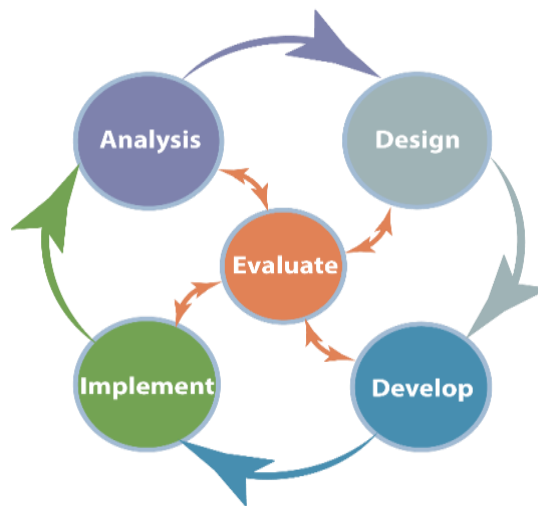


Figure 1. ADDIE Development model

Participant

The population of this study consisted of all Grade IX students at MTs Al Islah Laren. The sample was selected using purposive sampling based on specific criteria relevant to the research objectives. The study involved three groups: a limited trial group, an experimental group, and a control group. The experimental group used the developed Discovery Learning-based worksheets, while the control group used conventional learning materials. The selection of participants considered classroom characteristics and students' academic levels to ensure comparability between groups. All participants were involved in regular classroom learning activities during the study.

Instrument

Data in this study were collected using both qualitative and quantitative instruments. Qualitative data were obtained through interviews and observations to identify learning needs and evaluate the development process. Quantitative data were collected using validation sheets, questionnaires, and tests. The instruments used in this study are summarized in Table 1.

Table 1. Summary of instruments and data collection techniques

No	Data Type	Instrument	Technique
1	Learning needs	Interview	Interview
2	Learning process	Observation	Observation
3	Self-Regulated Learning	Questionnaire	Questionnaire
4	Mathematical literacy	Test	Test
5	Student responses	Questionnaire	Questionnaire
6	Product validity	Validation sheet	Expert review

Table 1 presents the relationship between data types, instruments, and data collection techniques. Each instrument was specifically designed to measure aspects aligned with the research objectives. Product assessment criteria.

Table 2. Validity criteria (likert scale)

Percentage Range	Category	Description
81% – 100%	Very Valid	Product is highly appropriate and meets all criteria
61% – 80%	Valid	Product is appropriate with minor revisions
41% – 60%	Fair	Product requires significant revision
< 41%	Invalid	Product is not suitable for use

Table 3. Practicality criteria

Percentage Range	Category	Description
81% – 100%	Very Practical	Easy to use, clear instructions, supports learning effectively
61% – 80%	Practical	Usable with minor improvements
41% – 60%	Fair	Requires significant improvements
< 41%	Not Practical	Difficult to use and ineffective

Table 4. Effectiveness criteria

Percentage Range	Category	Description
> 80%	Very Effective	High mastery and improvement in learning outcomes
60% – 79%	Effective	Majority of students achieve learning improvement
40% – 59%	Fair	Limited improvement observed
< 40%	Not Effective	No significant improvement

Instrument Reliability

Table 5. Reliability criteria (Cronbach's alpha)

Alpha Value	Category
≥ 0.90	Very High
0.70–0.90	High
0.60–0.70	Moderate
0.30–0.60	Low
< 0.30	Very Low

Data Analysis

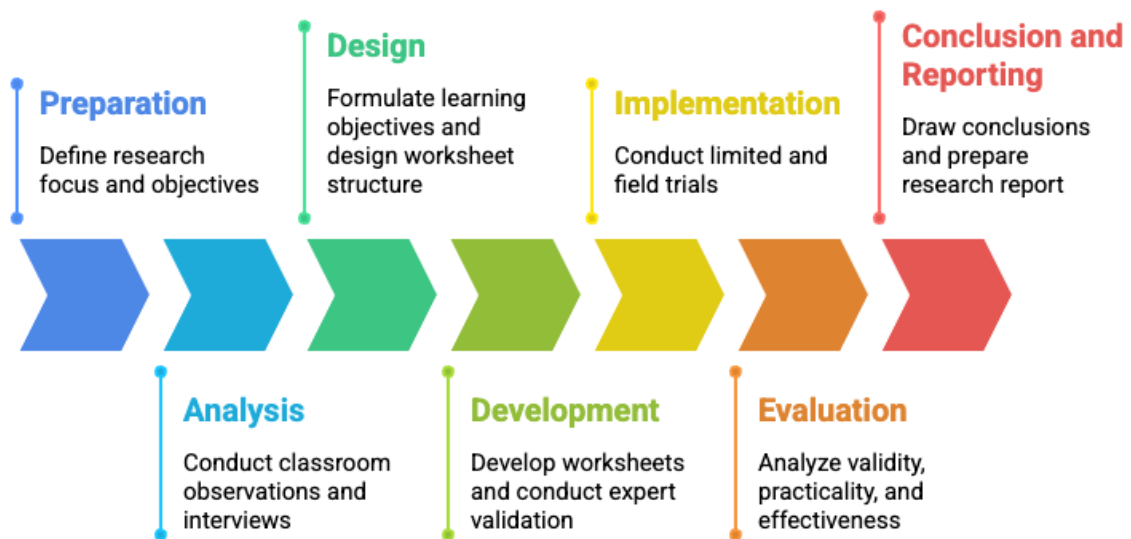
Data analysis was conducted using both descriptive and inferential statistical techniques. Descriptive analysis was used to evaluate validity and practicality based on expert assessments and student responses. The results were converted into percentages and categorized according to predefined criteria. Inferential analysis was used to assess the effectiveness of the worksheets. Prior to hypothesis testing, prerequisite tests were conducted to ensure data normality and homogeneity. The procedures are summarized in Table 6.

Table 6. Statistical analysis procedure

Stage	Test	Purpose	Criteria
1	Normality Test (Kolmogorov-Smirnov)	Check data distribution	Sig. > 0.05 (normal)
2	Homogeneity Test (Levene)	Check variance equality	Sig. > 0.05 (homogeneous)
3	Independent Samples t-test	Test differences between groups	Sig. < 0.05 (significant)

Procedure

The research procedure followed the ADDIE stages systematically. The study began with the analysis stage to identify learning problems and needs. This was followed by the design stage, where the structure and content of the worksheets were planned. The development stage involved creating and validating the worksheets. The implementation stage included limited and field trials in classroom settings. During this stage, students engaged in learning activities using the developed worksheets. Data were collected through tests and questionnaires. Finally, the evaluation stage involved analyzing the results to determine the quality of the worksheets. Revisions were made to improve the final product.

**Figure 1.** Research method flow

RESULTS AND DISCUSSION

Results

Analysis stage

The analysis stage was conducted to identify instructional needs based on real classroom conditions through classroom observations and interviews with mathematics teachers. The analysis focused on three main dimensions, namely the use of teaching materials, the characteristics of the learning process, and students' conceptual understanding of curved surface geometry. The findings revealed that existing instructional practices were still dominated by conventional approaches that relied heavily on textbooks and teacher-centered explanations. Consequently, students showed limited engagement and tended to act as passive recipients of information rather than active participants in learning. In addition, students' learning experiences were largely limited to textbook-based visualization without direct contextual representation, which constrained their ability to connect mathematical concepts with real-world situations. This condition contributed to students' difficulties in understanding abstract concepts, particularly those requiring spatial reasoning.

Furthermore, the absence of innovative and contextual instructional materials reduced opportunities for students to explore and construct their own understanding. These findings indicate a mismatch between the expected student-centered learning paradigm and the actual classroom practice.

Table 7. Results of needs analysis

Aspect	Findings	Implications
Teaching Materials	Teachers rely on textbooks and do not use LKPD	Learning is less varied and lacks student-centered activities
Learning Process	Dominated by teacher explanation and exercises	Students tend to be passive
Learning Experience	Limited real-life learning experience	Understanding remains superficial
Conceptual Understanding	Students struggle with concepts	Contextual approach is needed
Learning Needs	Lack of innovative materials	Need for Discovery Learning-based LKPD

As presented in Table 7, the analysis results clearly demonstrate that current instructional practices do not adequately support active learning or conceptual understanding. Therefore, the development of Discovery Learning-based worksheets integrated with cultural context is necessary to address these limitations and enhance the quality of mathematics learning.

Design stage

The design stage was conducted based on the findings from the analysis stage, with the aim of developing instructional materials capable of addressing the identified learning problems. The design of the LKPD focused on promoting student engagement, enhancing conceptual understanding, and providing meaningful learning experiences through contextual activities. The worksheets were structured according to the Discovery Learning model, ensuring that each stage of learning was systematically implemented. The LKPD design incorporated learning activities that encouraged students to actively explore concepts, formulate problems, collect and process information, and draw conclusions independently. In addition, the design integrated cultural elements derived from Hadroh musical instruments to provide concrete representations of abstract mathematical concepts. This integration aimed to bridge the gap between theoretical knowledge and real-life application, thereby improving students' comprehension and engagement.

Table 8. Structure of LKPD design

No	Component	Description
1	Title	Topic identification
2	Instructions	Guidelines for students
3	Learning Objectives	Competencies to be achieved
4	Stimulation	Contextual problem introduction
5	Problem Statement	Problem formulation
6	Data Collection	Information gathering
7	Data Processing	Data analysis
8	Verification	Validation of findings
9	Generalization	Concept conclusion
10	Exercises	Concept evaluation
11	Reflection	Self-evaluation

The structure presented in Table 8 indicates that the LKPD was systematically organized to facilitate the discovery learning process. Each component was designed to guide students through progressive stages of learning, ensuring coherence and continuity.

Table 9. Integration of discovery learning in LKPD

Stage	Implementation
Stimulation	Contextual problems
Problem Statement	Problem identification
Data Collection	Information exploration
Data Processing	Analysis activities
Verification	Concept validation
Generalization	Drawing conclusions

Table 9 shows that each stage of Discovery Learning was explicitly embedded within the worksheet design, ensuring that students engaged in a structured inquiry process.

Table 10. Learning activity design

Aspect	Description
Contextual	Real-life examples
Student Activity	Discussion and exploration
Independence	Self-directed learning
Mathematical Literacy	Problem-based tasks
Self-Regulated Learning	Reflection activities

The design of learning activities emphasizes both cognitive and metacognitive development. Students are encouraged not only to understand concepts but also to reflect on their learning processes, which supports the development of self-regulated learning.

Development stage

The development stage involved transforming the designed LKPD into a complete instructional product and conducting expert validation to assess its quality. Validation was carried out by experts who evaluated the worksheets based on content suitability, clarity of presentation, and instructional feasibility.

Table 11. Validation results

Aspect	Score
Content suitability	4
Presentation clarity	4
Instructional feasibility	3
Average	3.65 (91.17%)

The results presented in Table 11 indicate that the developed LKPD achieved a high level of validity, categorized as "very valid." This suggests that the worksheets meet the required standards in terms of content accuracy, clarity, and instructional design. Although minor revisions were suggested, the overall quality of the product was considered suitable for classroom implementation.

Implementation stage

The implementation stage was conducted to evaluate the practicality of the LKPD through student responses after its use in classroom learning. The results reflect students' perceptions regarding the ease of use, clarity of instructions, and visual design of the worksheets.

Table 12. Student responses

Aspect	Percentage
Ease of use	85%
Clarity of instructions	83%
Visual design	86%
Average	84%

The results show that the LKPD was categorized as “very practical,” indicating that students found the worksheets easy to use and helpful in facilitating learning activities. The high percentage across all aspects suggests that the design of the worksheets successfully supports usability and engagement.

Evaluation stage

Prerequisite testing

Before conducting hypothesis testing, prerequisite tests were performed to ensure that the data met statistical assumptions. The results of normality and homogeneity tests are presented in Tables 13–16. The normality test results indicate that all data are normally distributed, as the significance values are greater than 0.05. Similarly, the homogeneity test results show that the variance between groups is homogeneous. These findings confirm that parametric statistical analysis can be applied.

Hypothesis testing

Table 17. Independent sample t-test (mathematical literacy)

Indicator	Value
Sig. (2-tailed)	0.000
Mean Difference	10.248

The results indicate a statistically significant difference between the experimental and control groups, demonstrating that the use of Discovery Learning-based LKPD significantly improves students' mathematical literacy.

Table 18. Independent sample t-test (self regulated learning)

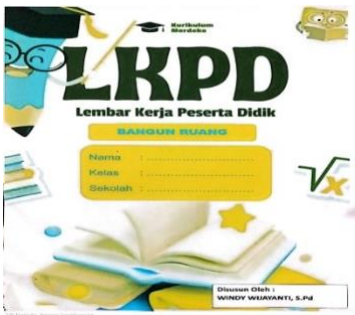
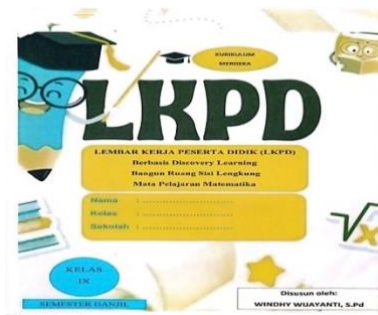
Indicator	Value
Sig. (2-tailed)	0.000
Mean Difference	2.859

Similarly, the results show a significant improvement in self-regulated learning among students who used the developed worksheets compared to those who used conventional materials.

Product revision

Following the evaluation stage, revisions were made to improve the quality of the LKPD based on expert feedback and implementation results.

Table 19. Product revision summary

No	Component	Revision	Before	After
1	Cover	Improved visual layout		

2	Terminology	Updated to CP and ATP		
3	Stimulation	Refined problem statements		
4	Data Collection	Simplified structure		
5	Data Processing	Improved clarity		

These revisions enhanced the usability, clarity, and alignment of the worksheets with Discovery Learning principles.

Discussion

The findings of this study demonstrate that the Discovery Learning-based worksheets integrated with the Hadroh cultural context meet the criteria of validity, practicality, and effectiveness, indicating their feasibility as an innovative instructional material in mathematics education. The high validity score suggests that the developed worksheets are well-aligned with content standards, instructional design principles, and the syntax of Discovery Learning. This alignment reflects the importance of coherence between pedagogical approaches and instructional materials in achieving effective learning outcomes. The integration of cultural context plays a significant role in strengthening the relevance of learning by connecting abstract mathematical concepts with students' real-life experiences (Acharya et al., 2021). This finding is consistent with previous studies that emphasize the importance of culturally responsive teaching in enhancing students' conceptual understanding and engagement (Abdulrahim & Orosco, 2020; Anyichie et al., 2023; Comstock et al., 2023; Cruz et al., 2020). Research in mathematics education has shown that

incorporating cultural elements into instruction can improve both cognitive and affective learning outcomes (Aprinastuti & Kovács, 2025; Chiu et al., 2022; Hui & Mahmud, 2023). In addition, contextual learning environments allow students to construct meaning more effectively by linking new knowledge with prior experiences. The present study extends these findings by demonstrating how cultural context can be systematically embedded within structured learning materials. This integration contributes to the development of more meaningful and engaging learning experiences. Therefore, the validity of the developed worksheets reflects both theoretical soundness and contextual relevance.

From the perspective of practicality, the results indicate that the worksheets are highly usable and effective in supporting student learning activities. The high practicality score suggests that students find the worksheets easy to use, well-structured, and supportive of independent learning. This finding aligns with previous research indicating that instructional materials with clear guidance and structured activities can significantly enhance usability and learning engagement (Almusharraf, 2024; Hidayati & Slamet, 2025; Lu et al., 2022; van Dulmen et al., 2023). Compared to conventional worksheets, which often emphasize repetitive exercises, the developed LKPD promotes exploration and interaction. This shift is important because active engagement has been shown to improve learning outcomes and student motivation. Studies in educational technology also highlight that well-designed learning materials can reduce cognitive load and facilitate comprehension (Bahari, 2023; Ibrahim et al., 2025; Refat et al., 2025). The inclusion of reflection activities in the worksheets further supports metacognitive processes, which are essential for self-regulated learning. Moreover, structured instructional design helps students navigate the learning process more effectively. In contrast, poorly designed materials may hinder learning by creating confusion and disengagement. Therefore, the high practicality of the developed worksheets confirms their effectiveness in facilitating active and independent learning.

The effectiveness results provide strong evidence that the use of Discovery Learning-based worksheets significantly improves students' mathematical literacy. The statistical analysis indicates a significant difference between the experimental and control groups, suggesting that the intervention has a measurable impact on learning outcomes (Kim & Castelli, 2021; Liu, 2025; Outhwaite et al., 2020). This finding is consistent with previous studies that have reported the positive effects of Discovery Learning on students' conceptual understanding and problem-solving abilities (Nusantari et al., 2021). The inquiry-based nature of Discovery Learning encourages students to actively construct knowledge, which enhances their ability to apply mathematical concepts in various contexts. Furthermore, the integration of cultural context provides meaningful learning situations that support the development of mathematical literacy (Kurniawan et al., 2023; Manfreda Kolar & Hodnik, 2021; Risdiyanti et al., 2024). Previous research has also demonstrated that contextual problem-based learning improves students' ability to interpret and apply mathematical knowledge in real-life situations. Compared to studies that focus solely on pedagogical approaches, this study highlights the added value of combining pedagogy with contextual relevance. The significant improvement observed in this study suggests that the integration of Discovery Learning and cultural context creates a synergistic effect. This combination enhances both conceptual understanding and application skills. Therefore, the findings confirm the effectiveness of this integrated instructional approach in improving mathematical literacy.

In addition to cognitive outcomes, the results show a significant improvement in students' self-regulated learning. This finding indicates that the developed worksheets not only support conceptual understanding but also promote students' ability to manage their own learning processes (M.-R. A. Chen & Hwang, 2020; Rohman et al., 2025; Suryawati et al., 2020). The structured stages of Discovery Learning provide opportunities for students to plan, monitor, and evaluate their learning activities (Aldalur & Perez, 2023; Subekti & Prahmana, 2021). These processes are essential components of

self-regulated learning and contribute to long-term academic success. Previous studies have emphasized that student-centered learning environments are more effective in developing metacognitive skills compared to traditional instruction (Bhardwaj et al., 2025; Ginting et al., 2024; Kerimbayev et al., 2023; Martin-Alguacil et al., 2024). The inclusion of reflection activities in the worksheets further strengthens students' awareness of their learning strategies. Moreover, the integration of cultural context enhances motivation, which is a key factor in self-regulated learning. Students are more likely to engage in learning when the content is relevant to their experiences. Compared to conventional learning approaches, which often limit student autonomy, the developed worksheets encourage active participation and independent learning. This shift toward learner autonomy is critical for developing lifelong learning skills. Therefore, the findings reinforce the importance of integrating cognitive and metacognitive elements in instructional design.

Despite the positive findings, this study has several limitations that should be considered. The research was conducted within a specific educational context with a limited sample size, which may affect the generalizability of the results. In addition, the study focused on a particular mathematical topic, which may not fully represent other areas of mathematics learning. The duration of the intervention was also relatively short, which may limit the observation of long-term effects. Previous research suggests that the impact of instructional innovations may vary depending on contextual and temporal factors. Therefore, future studies should explore the implementation of similar instructional approaches across different contexts and over longer periods. Furthermore, integrating digital technology into worksheet design could enhance interactivity and accessibility. Comparative studies involving different instructional models may also provide deeper insights into the effectiveness of various approaches. Investigating additional variables such as critical thinking and problem-solving skills would further enrich the findings. Despite these limitations, the study contributes to the growing body of research on innovative instructional design. Overall, the integration of Discovery Learning and cultural context represents a promising approach for improving both cognitive and metacognitive outcomes in mathematics education.

Implications

The findings of this study provide important implications for both theoretical and practical aspects of mathematics education. From a theoretical perspective, the study reinforces the effectiveness of integrating Discovery Learning with cultural context as a comprehensive approach to enhance both cognitive and metacognitive learning outcomes. This integration demonstrates that learning models are more impactful when supported by contextualized instructional materials that align with students' real-life experiences. In terms of instructional design, the results highlight the importance of developing structured learning materials that guide students through active exploration and concept construction. The use of culturally relevant contexts, such as Hadroh musical instruments, suggests that local culture can be effectively utilized as a pedagogical resource to make abstract mathematical concepts more meaningful. Practically, this study provides a model for teachers to design and implement student-centered learning materials that promote engagement and independence. The developed LKPD can serve as an alternative instructional tool that supports both mathematical literacy and self-regulated learning in classroom settings. In addition, the findings emphasize the need for teachers to shift from teacher-centered instruction to more interactive and inquiry-based approaches. The positive impact on students' learning outcomes indicates that integrating contextual and active learning strategies can improve the overall quality of mathematics education. Furthermore, this study suggests that curriculum developers should consider incorporating cultural elements into learning materials to enhance relevance and inclusivity. The results also imply that educational institutions should support the development and implementation of innovative instructional materials through training and professional development programs.

Ultimately, this study contributes to the advancement of mathematics education by offering a practical framework for designing meaningful, engaging, and effective learning experiences aligned with the demands of 21st-century education.

Limitations and Suggestions for Future Research

This study has several limitations that should be considered when interpreting the findings. First, the research was conducted in a single school with a relatively limited number of participants, which may restrict the generalizability of the results to broader educational contexts. Second, the study focused only on a specific mathematical topic, namely curved surface geometry, so the applicability of the developed worksheets to other mathematical topics remains uncertain. Third, the duration of the implementation was relatively short, which may not fully capture the long-term impact of the intervention on students' learning outcomes. Fourth, the measurement of self-regulated learning relied primarily on questionnaire data, which may be influenced by students' subjective perceptions. Fifth, the study did not include qualitative in-depth analysis such as interviews with students to explore their learning experiences more comprehensively. Sixth, the control group used conventional instructional methods without variations, which may limit comparative insights into other innovative approaches. Based on these limitations, future research is recommended to involve larger and more diverse samples across different educational settings. In addition, future studies should explore the implementation of similar instructional designs across various mathematical topics to examine their broader applicability. Researchers are also encouraged to conduct longitudinal studies to investigate the long-term effects of Discovery Learning-based worksheets on students' learning development. Furthermore, integrating qualitative methods such as interviews or classroom observations could provide deeper insights into students' learning processes. The incorporation of digital technology, such as interactive or web-based worksheets, is also recommended to enhance engagement and accessibility. Overall, further research is needed to refine and expand the use of culturally integrated Discovery Learning materials in mathematics education.

CONCLUSION

Based on the findings of this study, it can be concluded that the Discovery Learning-based student worksheets integrated with the Hadroh cultural context meet the criteria of validity, practicality, and effectiveness in mathematics learning. The validity results indicate that the developed worksheets are aligned with content requirements, instructional structure, and the characteristics of the Discovery Learning model. This alignment demonstrates that the product has been systematically designed to support meaningful and structured learning processes. The practicality findings show that the worksheets are easy to use and capable of facilitating independent learning activities among students. In addition, the clarity of instructions and the organization of learning activities contribute to effective classroom implementation. From the effectiveness perspective, the results reveal that the worksheets significantly improve students' mathematical literacy. Furthermore, the worksheets also enhance students' self-regulated learning by encouraging active participation, reflection, and self-monitoring during the learning process. The integration of cultural context plays an important role in making learning more relevant and engaging for students. This contextualization helps students connect abstract mathematical concepts with real-life experiences, thereby strengthening conceptual understanding. The study also highlights the importance of combining pedagogical approaches with culturally meaningful content in instructional design. Moreover, the findings suggest that student-centered learning supported by structured materials can improve both cognitive and metacognitive outcomes. Overall, the developed worksheets provide an innovative and effective alternative instructional material that supports the demands of 21st-century mathematics learning.

AUTHOR CONTRIBUTIONS STATEMENT

Fitriyanto Eko Subekti designed the study, developed the Discovery Learning-based student worksheets (LKPD) integrating the Hadroh cultural context, and led the research and development process using the ADDIE model, including validation, implementation, and effectiveness testing on students' mathematical literacy and self-regulated learning. Windhy Wijayanti contributed to the development of the theoretical framework on discovery learning and culturally contextualized mathematics instruction, refined the instructional design and structure of the LKPD, and supported data analysis, including validity, practicality, and inferential statistical testing. All authors contributed to writing, reviewed the manuscript critically for important intellectual content, and approved the final version

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