



Interactive Multimedia Technology for Geometry Learning: Integrating Ethnomathematics and Mobile Learning

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ABSTRACT

Purpose of the study: The study aims to develop and evaluate mobile learning media based on ethnomathematics, using Articulate Storyline integrated with a problem-based learning model, to support interactive, contextual and meaningful geometry learning for junior secondary school students.

Methodology: A research and development approach was employed using the ADDIE model. Participants consisted of 38 junior secondary school students involved in small- and large-scale trials. Data were collected through expert validation sheets, questionnaires and implementation evaluations. These were analysed using descriptive statistics, supported by percentage categories and triangulation from expert, teacher and student responses.

Main Findings: The developed mobile learning media were categorised as highly valid by experts in the field of media, subject matter and language. Implementation results indicate that the media is practical and well accepted by users. The findings also demonstrate its potential to support students' conceptual understanding of geometry and to enhance their interest in learning it through interactive multimedia features and culturally contextualised content from East Nusa Tenggara.

Novelty/Originality of this study: This study contributes to the field by integrating ethnomathematics, mobile learning and problem-based learning within a single instructional design using Articulate Storyline. Unlike previous studies that examined these approaches separately, this study emphasises the contextualisation of geometry concepts through local cultural elements, providing a culturally responsive, technology-enhanced learning approach.

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1. INTRODUCTION

Twenty-first-century mathematics education emphasizes the 6C competencies, which are creative thinking, critical thinking, communication, collaboration, computational thinking, and compassion, as foundations for competent and respectful interaction and effective learning [1], [2]. Within this agenda, critical thinking underpins reasoned instructional decision making and has remained a prominent focus of research over the past

two decades as a key twenty-first-century competency [3]–[5]. Beyond higher-order cognition, sustained engagement requires deliberate efforts to foster students' interest in mathematics.

Problem-based learning operationalizes learner-centered pedagogy by using authentic problems to drive active and collaborative knowledge construction [6]–[8]. Real-world contexts support creativity and problem-solving, promoting a deeper internalization of core concepts [9]–[11]. These findings reinforce the relevance of problem based learning, as it guides step-by-step proofs and encourages persistence in learning geometry topics [12]. Furthermore, ethnomathematics complements problem based learning by contextualizing learning and linking mathematical ideas to local cultural practices. This approach strengthens relevance, conceptual connectedness, and positive student attitudes toward mathematics [14], [15].

Preliminary observations and interviews conducted across eight junior secondary schools in Kupang revealed persistent difficulties in geometry, particularly solid geometry, rooted in a weak mastery of plane figures [15], [16]. Despite geometry's role in cultivating reasoning and critical thinking, classroom practice reveals an unsystematic use of ethnomathematics and a limited adoption of problem based learning, while commonly used media (physical aids, slide presentations, textbooks, web sources) insufficiently stimulate learning interest.

Given Gen Z learners' digital orientation, mobile, interactive, and accessible media are needed. Mobile learning (M-Learning) enables anytime, anywhere study via portable devices, supporting efficiency and effectiveness while fostering autonomy and interest [17]–[19]. Articulate Storyline 3 was selected as the development platform because it integrates text, images, audio, video, animations, and simulations within an interactive ecosystem that is compatible across platforms and can be published to HTML5 or app formats and accessed on laptops, tablets, and smartphones [20]–[22]. These characteristics align the intervention with students' study habits, enhancing accessibility, interactivity, and engagement [23]–[25].

Prior studies indicate that using Articulate Storyline 3 can increase motivation and improve learning achievement [26]–[28]. Problem based learning has been shown to strengthen mathematical reasoning, enhance critical thinking and creativity, and promote higher-order thinking [29]–[31]. Integrating ethnomathematics into school mathematics positively affects processes and outcomes, including in combination with problem based learning to reinforce problem solving and mathematical literacy [32]–[34]. Building on this rationale, the present study develops ethnomathematics-based M-Learning using Articulate Storyline 3 within a problem based learning model for junior secondary geometry in Kupang, with the primary aim of increasing students' interest in mathematics [35]–[38]. Specifically, the study seeks to: (i) produce M-Learning media validated in content, language, interface, and usability; (ii) evaluate acceptability and practicality from teacher and student perspectives; and (iii) explore effects on students' interest and engagement in learning geometry. Interest in learning is retained as the principal outcome variable, whereas critical thinking indicators are examined descriptively as potential ancillary effects.

Previous studies have demonstrated that Articulate Storyline is effective in enhancing learning motivation and achievement, while problem-based learning has been shown to improve students' critical thinking, creativity, and problem-solving abilities. In addition, ethnomathematics contributes positively to students' motivation, mathematical understanding, and cultural awareness by connecting mathematical concepts with local cultural practices. However, most previous studies have examined these approaches separately, and limited research has integrated ethnomathematics, mobile learning, and problem-based learning within a single instructional design. Furthermore, existing studies have largely focused on general mathematics topics without contextualizing geometry through local cultural elements, particularly in East Nusa Tenggara. This indicates a need for a culturally responsive and technology-enhanced learning medium that can make geometry learning more meaningful and engaging.

In the current digital era, mobile learning and interactive multimedia have become increasingly important in supporting flexible, engaging, and student-centered learning environments. Despite the widespread use of smartphones among students, culturally contextualized learning media remain limited. Therefore, this study introduces an innovative approach by integrating ethnomathematics, interactive mobile learning, and problem-based learning through Articulate Storyline. This integration not only emphasizes technological innovation but also promotes culturally responsive pedagogy in geometry learning. The objectives of this study are threefold: (1) to develop a valid and feasible ethnomathematics-based mobile learning medium for geometry learning; (2) to evaluate its practicality and acceptability from teacher and student perspectives; and (3) to examine its potential to enhance students' interest and engagement in learning geometry.

2. RESEARCH METHOD

The media were developed using the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), which was introduced by Dick and Carey in 1996 [39]. The population of this study comprised junior secondary school students in Kupang. A total of 38 students were selected for the study using purposive sampling: The number of participants required for the small-scale trial was 15, and 23 for the large-scale trial. The participants were eighth-grade students between the ages of 13 and 14. The research instruments employed in this

study comprised validation sheets, questionnaires, and interview guidelines. In addition, a usability questionnaire was employed to evaluate user experience aspects, including ease of use, navigation, interface design, and overall user satisfaction with the mobile learning application.

The validity of the study was ensured through expert judgment, and reliability was measured using Cronbach's alpha. The analysis of the data was conducted using descriptive statistics, underpinned by percentage categories and mean scores. In order to consolidate the findings, a process of triangulation was undertaken, whereby the data was combined with expert validation, responses from students, and teacher feedback. The ADDIE model delineates five phases: The following five stages must be considered: (1) analysis, (2) design, (3) development, (4) implementation, and (5) evaluation. In this study, the model was adapted as follows:

2.1 Analysis

Needs analysis involved teachers and junior secondary students. It identified the need for M-Learning media, supported by Articulate Storyline 3, for ethnomathematics-based geometry within a problem based learning syntax. The analysis also reviewed learner characteristics, Core Competencies, Basic Competencies, and Indicators of Competency Achievement. A literature review was also included. At this stage, relevant elements of ethnomathematics for East Nusa Tenggara geometry were examined.

2.2 Design

A flowchart was created to illustrate the programme's workflow. A storyboard was used to outline the layout and interface. Content planning covered instructional materials and assessment items. These were delivered using Articulate Storyline 3. The geometry content, based on ethnomathematics, followed the PBL instructional syntax. Figure 1 below shows the flowchart for this learning material.

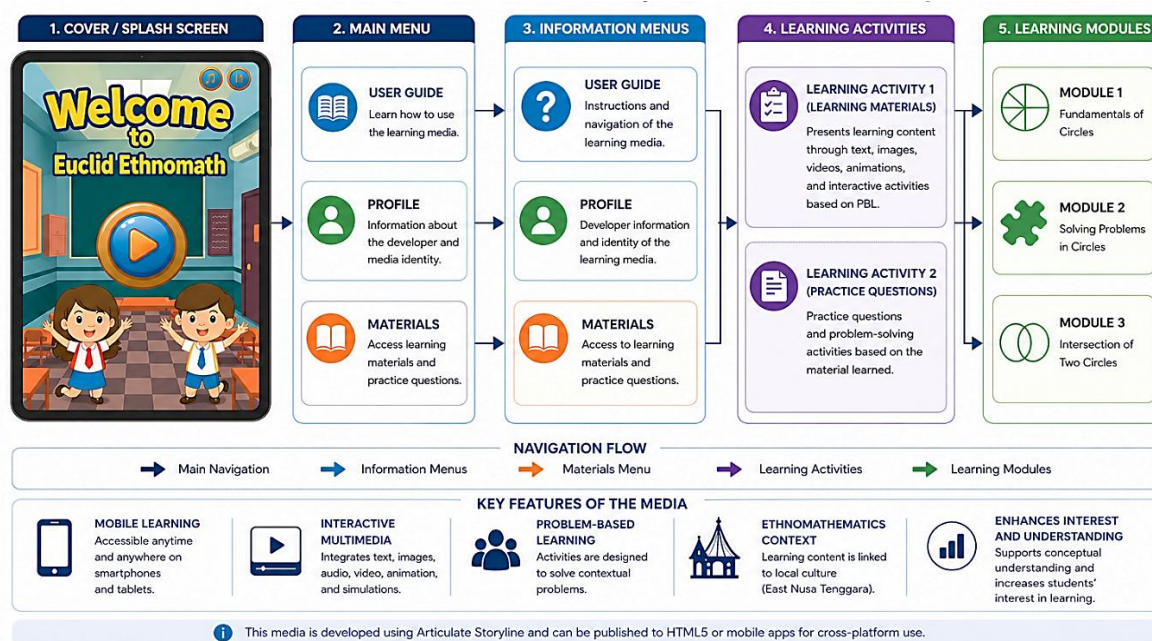


Figure 1. Flowchart of instructional media

2.3 Development

The designed media were realized for pilot testing in Phase 4. The first draft of the M-Learning media (Articulate Storyline 3, ethnomathematics-based geometry, problem based learning) was reviewed by one media expert, one subject-matter expert, one language expert, and five teachers. Experts provided feedback, which led to the development of Draft 2. Data analysis used both qualitative and quantitative methods. Qualitative analysis covered notes, feedback, opinions, and teacher interview results. Quantitative analysis was for questionnaire data. Expert feasibility judgments were grouped into four categories, summarized in Table 1 (Feasibility Rating Scale).

Table 1. Feasibility Assessment Rating Scale

Criteria	Score
Excellent	4
Good	3
Poor	2
Very poor	1

Subsequently, the experts' feasibility quality score was obtained using the following formula:

$$\text{Score} = \frac{\text{Observed Score}}{\text{Maximum Score}} \times 100\% \quad \dots (1)$$

The resulting percentage was then interpreted for the feasibility test score [34] as presented in Table 2.

Table 2. Formatting Rules

Interval	Category	Description
$3.25 < x \leq 4.00$	Highly valid	Implementable without revision
$2.50 < x \leq 3.25$	Valid	Implementable with minor revisions
$1.75 < x \leq 2.50$	Marginally valid	Implementable with major revisions
$1.00 < x \leq 1.75$	Not valid	Not implementable and consultation required

These percentages are supported by expert and student feedback. The researcher then summarizes findings and draws conclusions for each aspect of the instructional media.

2.4. Implementation

This phase focused on the implementation of the pilot study and the collection of preliminary data. A small-scale trial was conducted with 15 eighth-grade students at State Junior High School 16 Kupang. The goal was to identify technical issues, evaluate navigation ease, and review the Problem-Based Learning flow within an ethnomathematics context. Findings from this stage informed several minor refinements. Following the revision, a large-scale trial was conducted with 23 eighth-grade students at St. Joseph Catholic Junior High School. This trial examined the acceptability and consistency of use across a different school context. At the end of each session, data were collected through student questionnaires and open-ended responses. Brief teacher feedback was also gathered.

2.5. Evaluation

This phase was conducted after the small- and large-scale trials to assess the feasibility, acceptability, and impact of the media on students' learning experiences. Data were collected using a Likert-scale questionnaire covering five aspects: interface and usability, content, ethnomathematics and cultural context, problem-based learning, and motivation and perceived benefits.

In addition, the usability of the developed media was evaluated using an 18-item questionnaire distributed across five dimensions: interface design and usability, content quality, ethnomathematics and cultural context, problem-based learning aspect, and motivation and perceived benefits. Respondents were asked to rate each item using a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5). The instrument was validated through expert judgment prior to implementation. The questionnaire was administered after the trial sessions, and descriptive statistics were used to determine usability levels. Table 3 presents the blueprint of the usability questionnaire, including its dimensions, number of items, and key indicators.

Table 3. Blueprint of Usability Questionnaire Instrument

Dimension	Number of Items	Indicators
Interface Design and Usability	4	Visual appearance, navigation, controls, readability
Content Quality	4	Clarity, relevance, organization, multimedia support
Ethnomathematics and Cultural Context	3	Cultural relevance, contextual understanding, learning interest
Problem-Based Learning Aspect	3	Active thinking, problem-solving, real-life analysis
Motivation and Perceived Benefits	4	Motivation, independent learning, enjoyment, usefulness
Total	18	

Open-ended items invited suggestions and areas for improvement. The evaluation subjects were the eighth-grade students who participated in the implementation. Teachers provided brief feedback on classroom applicability. Data collection took place immediately after the media sessions. Students completed the questionnaire, while teachers filled out an evaluation form. The researcher also recorded concise observations of problem based learning enactment. Quantitative data were analyzed descriptively to compute the percentage of positive responses and item-level means for each aspect. Qualitative data were analyzed thematically to cluster suggestions into development themes. These themes informed recommendations for the next iteration of the media.

3. RESULTS AND DISCUSSION

A development study of ethnomathematics-based M-Learning media, supported by Articulate Storyline and employing a problem based learning model, was conducted using the ADDIE development framework (Analysis, Design, Development, Implementation, and Evaluation) [41]. The findings for each phase are presented as follows.

3.1. Analysis phase

In the analysis phase, a needs assessment was conducted with junior secondary teachers and students to establish the necessity of M-learning media supported by Articulate Storyline 3 for ethnomathematics-based geometry using a problem based learning approach. The analysis also covered learner characteristics, including Core Competencies and Basic Competencies, as well as Indicators of Competency Achievement, and a focused literature review. The needs assessment involved all eighth-grade students at two schools: St. Yoseph Catholic Junior High School, Kupang, and State Junior High School 16 Kupang. It utilized questionnaires, as illustrated in Figures 2-3 below.



Figure 2. Distribution of the needs analysis questionnaire at State Junior High School 16 Kupang



Figure 3. Distribution of the needs analysis questionnaire at St. Joseph Catholic Junior High School.

In Figures 2–3(a), the researcher distributed the questionnaires to the students, and in Figures 2-3(b) and 3(c), the students completed the needs-analysis questionnaire. Based on the analysis of the student needs-assessment data, a profile of students' use of and perceptions toward mathematics instructional media was obtained. The findings indicate that most students (72.88%) had used instructional media in learning mathematics, whereas 27.12% had not. This suggests that media use is already prevalent among students, although a minority have not yet adopted it optimally.

Regarding the types of media, text-based materials (textbooks, notes, and similar resources) were most frequently used (66.10%), followed by visual media such as graphs, diagrams, and illustrations (33.90%). No students reported using audio- or video-based media. These results indicate that mathematics instruction in schools remains dominated by conventional text-based press, with limited adoption of interactive digital media. In terms of perceived effectiveness, students rated the media as fairly effective (38.98%) and effective (33.90%) in supporting conceptual understanding; 13.56% considered them ineffective, and 13.56% rated them very effective. This indicates a generally positive contribution to conceptual understanding, while highlighting room for improvement through more engaging and interactive innovations.

By usage frequency, most students reported using mathematics instructional media often (38.98%) or fairly often (37.29%) each week, while 20.34% reported using them occasionally, and 3.39% reported using them consistently. This suggests a relatively high intensity of use, although consistency requires improvement. With respect to motivation, students expressed positive responses: most felt motivated (38.98%) or fairly motivated (37.29%), while 20.34% felt unmotivated and only 3.39% felt very motivated. Thus, media use plays a crucial role in stimulating learning motivation; however, further refinement is necessary to optimize its motivational impact.

Moreover, all students (100%) stated that they had never used Articulate Storyline 3-based media, yet all (100%) agreed that computer-based media should be developed to support classroom mathematics. This reflects both a need for and readiness toward modern, interactive, and accessible digital media. In terms of learning preferences, students identified learning applications as the most suitable medium (57.63%), followed by audio (28.81%), text (23.73%), video (25.42%), and visual media (18.64%). This indicates a preference for interactive app-based media that enable engaging, self-directed learning.

Students also judged that instructional content should be presented in ways relevant to the cultural environment: 40.68% reported it as “strongly necessary,” 30.51% as “necessary,” and 28.81% as “moderately necessary.” This highlights the importance of integrating local cultural contexts to ensure meaningful and contextually relevant learning. In addition, most students considered the use of pertinent mathematical media examples to be very important (49.15%) or essential (37.29%) for aiding conceptual understanding. Hence, media that connect content to real-world situations or local culture are believed to enhance knowledge and interest in mathematics. Overall, the analysis suggests that students have positive experiences with instructional media. Nevertheless, there remains a need for more interactive, contextual, and engaging computer-based press, such as Articulate Storyline-based M-learning integrated with local wisdom, to enhance motivation, effectiveness, and relevance in school mathematics.

3.2. Design phase

In this phase, the researcher prepared the instructional media flowchart and storyboard, whose core structure comprises the home screen, user instructions, developer profile, instructional content, and evaluation. The developed content covers ethnomathematics-based geometry from East Nusa Tenggara Province, focusing on cultural contexts such as traditional house forms and Manggarai lodok patterns, as illustrated in Figures 4 and 5 below.



Figure 4. Traditional houses in the regions of East Nusa Tenggara



Figure 5. 'Lodok' cultural heritage

The ethnomathematics-based geometry content was designed in accordance with the syntax of the problem based learning model [42], as outlined in Table 4 below.

Table 4. Problem based learning syntax in the M-learning instructional media

Interval	Category	Description
Problem orientation	Problem orientation	Provide salient facts about the contextualized topic
Problem definition	Problem definition	Guide students step by step to formulate the problem
Guide individual and group inquiry	Fact finding	Guide students to gather and organize information
	Drafting candidate solutions	Coach students to propose provisional solution alternatives
Developing and presenting outcomes	Information investigation	Guide students to investigate and refine the proposed solutions
Analyzing and evaluating the problem solving process	Collaborative analysis of alternative solutions	Guide students to conclude on the most viable alternative
	Testing the solution	Synchronize the solution with the original problem to check its realism and fit

3.3. Development phase

In this phase, the media design was implemented in Articulate Storyline 3, featuring interactive multimedia content, text, images, animations, videos, and ethnomathematics-based quizzes, as illustrated in Figures 6–11 below.



Figure 6. Cover page



Figure 7. Main menu page



Figure 8. User guide menu page

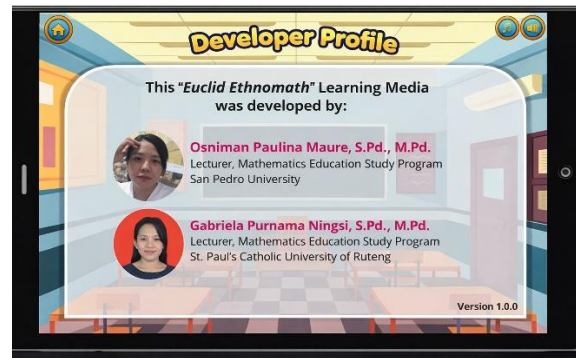


Figure 9. Developer profile page



Figure 10. Learning menu page

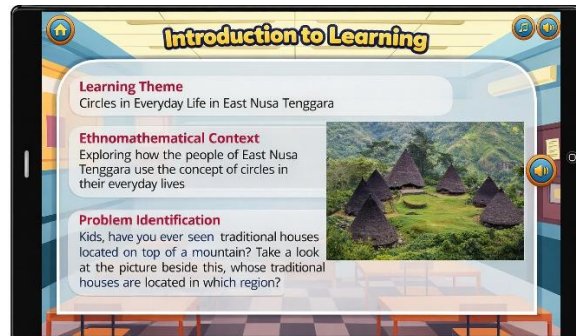


Figure 11. Introduction to learning page

Subsequently, the draft of the instructional media, consisting of Articulate Storyline 3 with an ethnomathematics-based problem based learning approach, underwent a feasibility evaluation through expert validation by media experts, subject-matter experts, language experts, and practitioners (teachers). Experts and practitioners will use a product validation questionnaire when assessing the draft. The media-expert validation instrument covers interface design, audio, animations, and user-friendliness. After validation, the completed questionnaires are processed and analyzed. The validation results provided by experts and practitioners are then interpreted in accordance with the product-fit interpretation guidelines in Table 3, and the outcomes are presented in Figure 12.

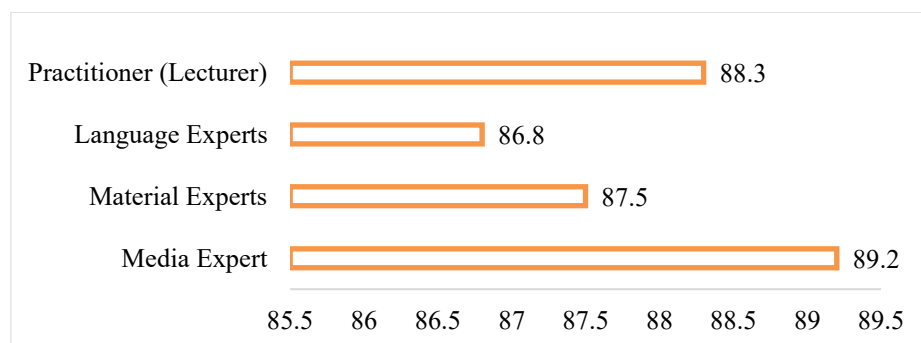


Figure 12. Expert validation results

Figure 12 indicates that the media expert awarded an average score of 89.2% (highly valid category), the subject-matter expert 87.5% (highly valid), the language expert 86.8% (highly valid), and the practitioners (teachers) 88.3% (highly valid). These findings suggest that the developed instructional media meet the feasibility standards for interface design, content appropriateness, linguistic quality, and user-friendliness, thereby rendering them suitable for implementation with minor revisions.

3.4. Implementation and evaluation phases

A small-scale trial was conducted with 15 eighth-grade students at State Junior High School 16 Kupang to identify technical issues, evaluate ease of navigation, and examine the implementation of the Problem-Based Learning flow within an ethnomathematics context. Findings from this trial were used to make minor revisions to the developed media. Subsequently, a large-scale trial was carried out with 23 eighth-grade students at St. Joseph Catholic Junior High School to examine the acceptability, consistency of use, and practicality of the media in a different school setting. These implementation activities are presented in Figures 13–14 below.



Figure 13. Small-scale trial at Partner School 1



Figure 14. Large-scale trial at Partner School 2

3.5. Evaluation phases

Upon completion of the implementation phase, students were asked to complete an evaluation questionnaire administered through Google Forms. The instrument covered five aspects: interface and usability, content quality, ethnomathematics and cultural context, problem-based learning, and motivation and perceived benefits. In addition, open-ended questions were provided to gather suggestions, feedback, and recommendations for improving the application. The questionnaire results for these five aspects are presented in Figures 15–19 below.

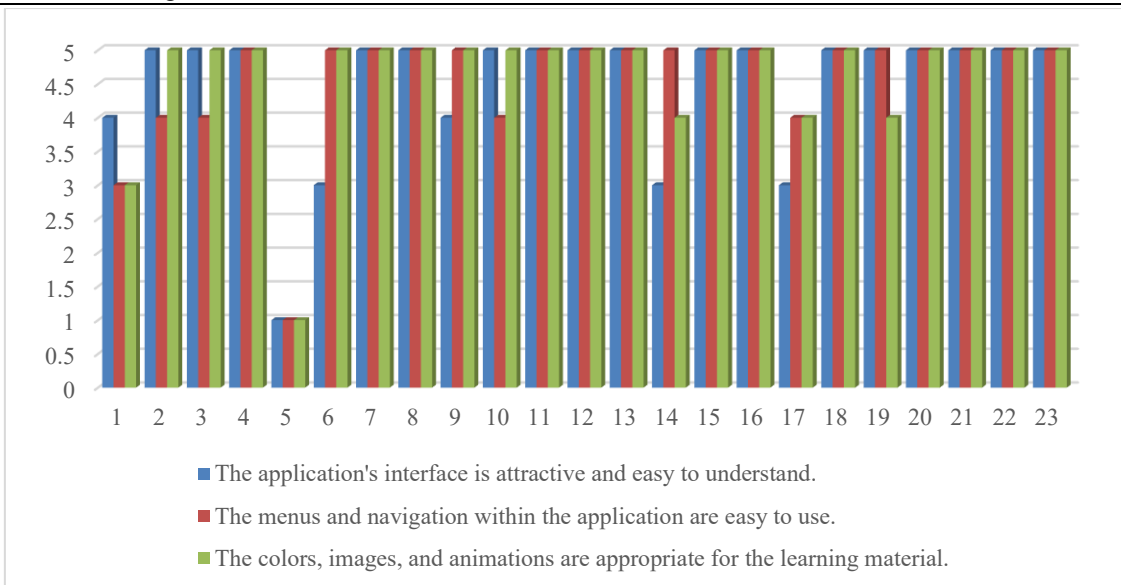


Figure 15. Questionnaire results for interface and usability

As shown in Figure 15, respondents’ ratings display a strongly positive and mutually reinforcing pattern across the three indicators under review. The application was judged visually appealing, easy to understand, and easy to navigate by most respondents. For the first item, 17 respondents (73.9%) assigned a score of 5, and 2 respondents (8.7%) assigned a score of 4, resulting in a total positive rating of 82.6%. Only a small proportion gave moderate or low scores, indicating limited scope for refinement, while the application’s visuals were generally rated as very strong.

For the second item, 17 of 23 respondents (73.9%) gave a score of 5, and 4 respondents (17.4%) gave a score of 4. Thus, 91.3% rated the navigation features very favorably, with only two respondents assigning low scores (4.3% each), suggesting minimal barriers to use. For the third item, 18 respondents (78.3%) awarded a score of 5 and 3 respondents (13%) a score of 4, bringing the share of positive ratings again to 91.3%. Low scores were given by only two respondents (4.3% each), indicating that the visual elements effectively support conceptual understanding.

Overall, the predominance of high scores across all three indicators underscores the application’s primary strengths in aesthetic design, visual clarity, and ease of navigation, which together contribute to a smooth and satisfying user experience. Potential improvements are minor and may focus on harmonizing color schemes and iconography to enhance coherence and inclusivity for diverse user preferences, without requiring substantial structural changes.

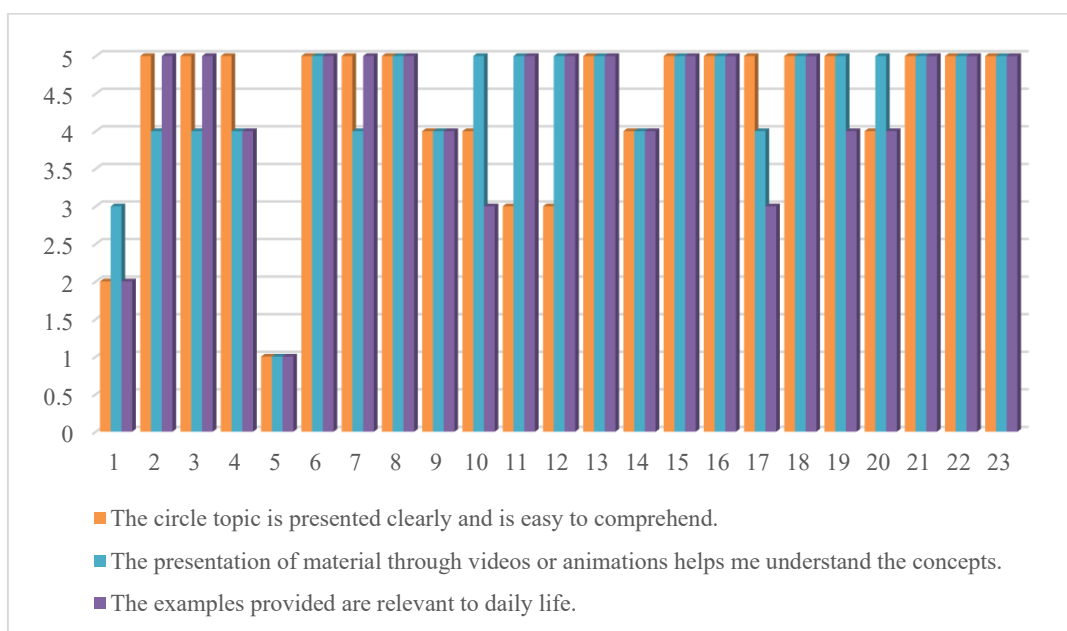


Figure 16. Questionnaire results for the content aspect

As shown in Figure 16, respondents' ratings exhibit a strongly positive and consistent pattern across the three indicators. Presenting content through videos or animations was perceived to support conceptual understanding, with 14 of 23 respondents awarding a score of 5 (60.9%) and seven awarding a score of 4 (30.4%); thus, a large majority judged the media effective, and only two respondents assigned scores of 1 and 3 (4.3% each). Furthermore, the examples provided were viewed as relevant to everyday life, as reflected by 14 respondents selecting a score of 5 (60.9%) and five selecting a score of 4 (21.7%). In contrast, low scores at levels 1, 2, and 3 were observed in tiny proportions. For the indicator of content clarity, particularly the circle topic, 15 respondents awarded a score of 5 (65.2%) and four awarded a score of 4 (17.4%), with only a small number choosing scores of 1, 2, or 3.

Descriptively, these findings confirm that the quality of content delivery, in terms of conceptual clarity, the relevance of examples, and the support provided by video or animation, has effectively met the learning needs of most participants. Practical implications suggest that improvements are minor and may be targeted toward users who provided mid-to-low ratings, for example, by offering a broader variety of examples, step-by-step explanations for difficult sub-concepts, and video playback controls (pause, replay, speed) to make the learning experience more adaptive to individual needs.

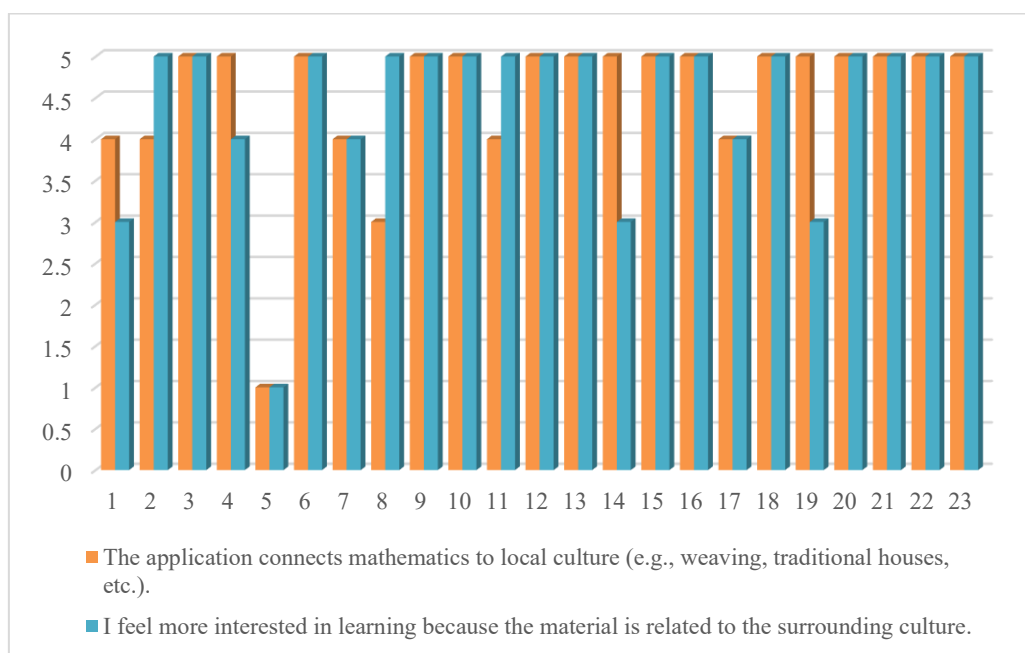


Figure 17. Questionnaire results for the ethnomathematics and cultural context aspect

As shown in Figure 17, respondents expressed strong appreciation for linking content to local culture. For the statement “I am more interested in learning because the material is connected to the surrounding culture,” 16 of 23 respondents assigned a score of 5 (69.6%) and three respondents a score of 4 (13%), indicating that a clear majority perceived increased learning interest, with only a small number assigning scores of 1 or 3. Consistently, the statement “This application connects mathematics with local culture (weaving, traditional houses, and the like)” also received very positive ratings, with 16 respondents awarding a score of 5 (69.6%) and five respondents a score of 4 (21.7%), while low scores were nearly absent.

Descriptively, these findings affirm that integrating local culture, such as weaving motifs and traditional house architecture, meaningfully enhances students' engagement and interest in mathematics. Practical implications include broadening the range of cultural exemplars to be more inclusive for all respondents, particularly by adding more diverse cultural representations, enriching relevant visuals, and explicitly mapping mathematical concepts (e.g., patterns, symmetry, plane figures) to local cultural artifacts. In turn, subsequent development can maximize contextual relevance while maintaining consistency in content presentation across students' diverse cultural backgrounds.

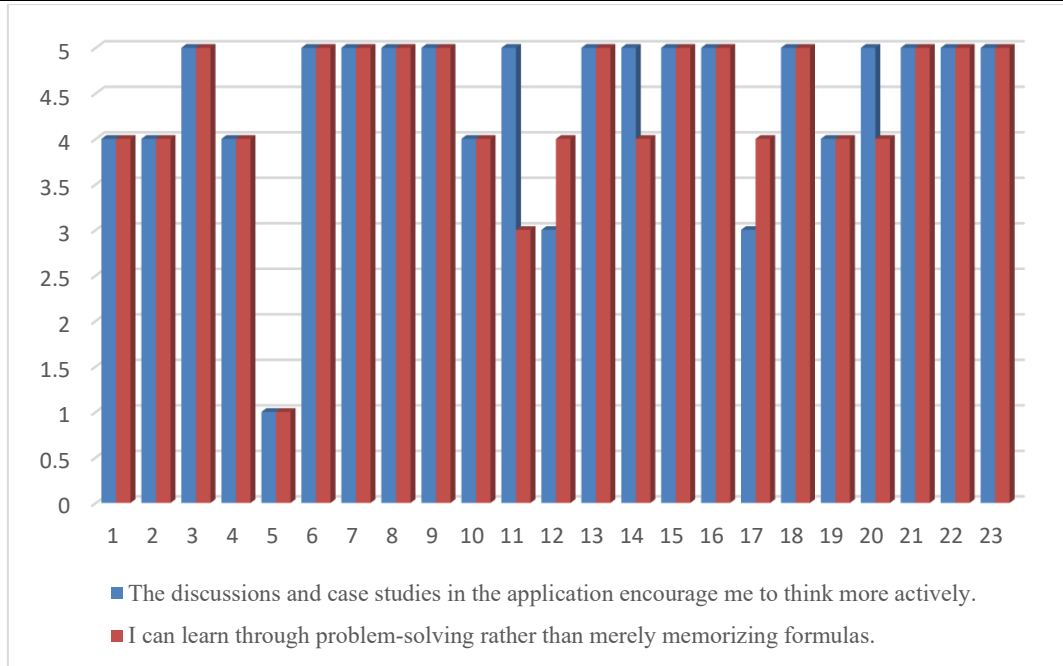


Figure 18. Questionnaire results for the problem-based learning aspect

As shown in Figure 18, respondents expressed strong support for the problem-based approach implemented in the application. For the first item, 15 of 23 respondents awarded a score of 5 (65.2%), and five respondents a score of 4 (21.7%). Low scores were observed in tiny proportions, indicating that most participants experienced increased active thinking through discussion and case studies. Consistently, for the second item, 12 respondents assigned a score of 5 (52.2%) and nine respondents a score of 4 (39.1%). Two respondents selected scores of 1 and 3, suggesting that the problem based learning approach tends to foster conceptual understanding rather than rote memorization for the majority of users.

Descriptively, these results affirm that the discussion features, case studies, and problem-solving tasks have been effective in enhancing students’ cognitive engagement. Areas for improvement may focus on offering a broader variety of cases and scaffolding difficulty levels, thereby promoting a more even and inclusive learning experience for all users.

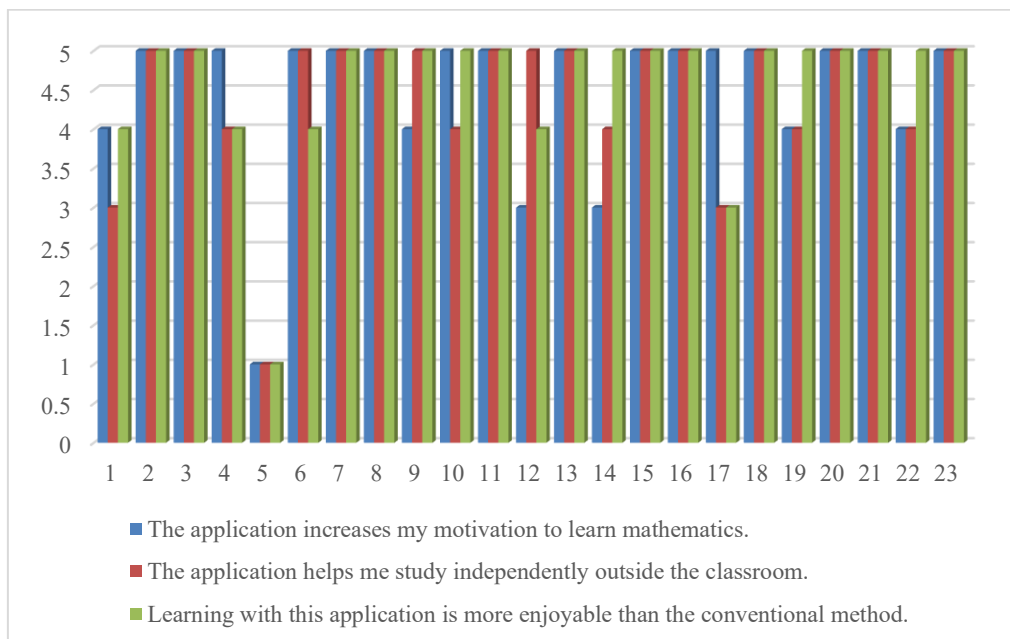


Figure 19. Questionnaire results for the motivation and perceived benefits aspect

As shown in Figure 19, respondents’ ratings indicate a substantial positive impact on learning interest, learner autonomy, and the overall learning experience. For the first item, 16 of 23 respondents assigned a score of

5 (69.6%), and four respondents assigned a score of 4 (17.4%), with only a small minority selecting scores of 1 or 3, indicating a clear motivational boost for most users. For the second item, 15 respondents awarded a score of 5 (65.2%) and five respondents a score of 4 (21.7%), underscoring the application's role in supporting self-directed learning. In contrast, low scores again appeared in tiny proportions. Consistently, for the third item, 17 respondents gave a score of 5 (73.9%), and four respondents gave a score of 4 (17.4%), indicating that the majority found the learning experience more enjoyable. Descriptively, these three results confirm that the application not only enhances motivation but also facilitates learner autonomy and fosters a more enjoyable learning environment. Potential refinements may focus on accommodating individual preferences among those who provided mid-to-low ratings to equalize perceived benefits further.

The findings presented across the analysis, design, development, implementation, and evaluation phases demonstrate that the developed ethnomathematics-based M-Learning media supported by Articulate Storyline and integrated with the Problem-Based Learning approach was positively received by students and experts. Beyond the descriptive findings, the results also provide important insights into how interactive multimedia, contextual cultural integration, and problem-based activities contribute to students' motivation, engagement, and conceptual understanding in mathematics learning. Therefore, the following discussion interprets these findings in relation to existing theories and previous studies.

These findings can be further interpreted in relation to existing theories and prior studies to better understand their implications. Beyond the quantitative findings, brief open-ended responses revealed strong appreciation for the instructional media in terms of ease of understanding, visual design, and practical learning benefits. Respondents repeatedly described the material as "easy to understand," the visuals as "good/attractive," and highlighted the helpful role of videos, leading them to judge the media as effective, enjoyable, and conducive to faster thinking. The inclusion of cultural context, particularly from East Nusa Tenggara, along with relevant examples and motifs/images was also valued for enhancing interest in mathematics and enriching general knowledge. Overall, the comments affirm that the media are practical, effective, and enjoyable to use, and that its overall concept is well received.

Based on open-ended responses to the "Areas for improvement" item, user feedback clustered around two major themes: content expansion and interface/feature refinement. First, most suggestions emphasized broadening instructional coverage, expressed in phrases such as "add other subjects/topics," "include more subjects," and "can you add more material?" indicating a primary need for a wider and tiered content scope. Second, respondents proposed enhancements to the user experience, including "making the interface more engaging and more colorful" and a preference for more contextualized examples (e.g., "replace the circle with a soccer ball"), reflecting a desire for visuals and examples that are closer to students' daily lives. Additionally, one comment concerned audio/music, suggesting that sound controls would be helpful. The many "nothing needs to be improved" responses confirm a high level of satisfaction with the application in its current state; therefore, improvement efforts can be prioritized toward a roadmap for content growth, aesthetic refreshes, contextual example presentation (e.g., sports), and the addition of audio controls without significant structural changes.

These findings can be further interpreted in relation to existing theories and prior studies to better understand their implications. The high validity evidence demonstrates adherence to interactive multimedia design principles, specifically the integration of text, visuals, animation, audio, and assessment within a coherent multimedia framework. The implementation results showed improvements in learning outcomes and conceptual understanding after the use of interactive multimedia, strengthening the argument that the application of multimedia principles contributes to improving mathematics learning outcomes [43].

The consistency of these results is reflected in expert validation and practicality testing across several studies, which classify the media as highly feasible or highly practical, alongside gains in learning outcomes and students' conceptual understanding of mathematics [40], [44]. Effectiveness tests further corroborate that the PBL model significantly enhances critical thinking skills [24]. In addition, integrating ethnomathematical contexts has been shown to strengthen the real-world relevance of content and to improve mathematical communication and connections [33], [45], [46].

The findings further indicate that the technological features embedded in the developed media made substantial contributions to students' learning experiences. Interactive elements, such as animations, videos, quizzes, navigation menus, and immediate feedback, helped learners more easily understand abstract geometry concepts while sustaining their attention during learning activities. These multimedia components supported diverse learning preferences by combining visual, textual, and interactive representations on a single platform [20]-[24]

Additionally, the mobile learning format increased student engagement by enabling access anytime, anywhere, via smartphones. Since students are highly familiar with mobile devices, the application created a more enjoyable, learner-centered, and self-directed learning environment. Students could review materials repeatedly, learn independently, and actively participate in contextual problem-solving tasks. This positively influenced their motivation and interest in mathematics [17], [18], [47], [48].

Compared with conventional media, such as textbooks, static slide presentations, and teacher-centered explanations, the developed mobile learning media provided a more dynamic and interactive learning experience. Conventional media often lack visualization, learner interaction, and immediate feedback [49], [50]. In contrast, the present application integrates multimedia resources and ethnomathematics-based contexts that make learning mathematics more meaningful and engaging [43], [51], [52].

The needs analysis indicates a requirement for interactive and contextual geometry media, as classroom practices remain dominated by text-based materials, despite being regarded as fairly effective. Students' preference for application-based learning and support for integrating local culture underpin the development of ethnomathematics-based M-Learning. The problem based learning model was selected because it connects concepts to real-world situations, thereby aligning with students' experiences [6], [53], [54]. Within this framework, development is oriented toward bridging the gap between learning needs and the availability of appropriate media.

The design phase encompassed the preparation of flowcharts and storyboards incorporating the home interface, guidance, profile, content, and evaluation to ensure a systematic learning pathway. Cultural contexts from East Nusa Tenggara, such as traditional houses and the lodok pattern, were used as conceptual anchors to bring the content closer to local realities. The problem based learning syntax was structured from problem orientation through reflection to form a complete and consistent learning cycle. Clarity of flow and interface consistency were established as the foundation for a seamless user experience in the subsequent development stage.

During development, the design was implemented in Articulate Storyline 3, combining text, images, animations, videos, and quizzes to accommodate diverse learning styles. Validation by media, subject-matter, and language experts, as well as practitioners, placed the product in the highly valid category, rendering it ready for field testing. Implementation through small- and large-scale trials confirmed the ease of navigation, visual appeal, and the clarifying role of videos and animations in enhancing conceptual understanding. Descriptive evaluation revealed predominantly positive ratings and thematic suggestions that informed the next iteration, including content expansion, aesthetic refreshes, stronger contextual examples, and the addition of audio controls.

A growing body of research demonstrates improvements in mathematical critical thinking through problem-solving activities. Indicators of interpretation, analysis, evaluation, and inference tend to increase when students engage in discussion and case studies. This tendency is reflected in the implementation of PBL within the media, which stimulates active thinking. Problem based learning fosters stronger conceptual understanding than rote-oriented instruction. Ethnomathematics literature shows that integrating local culture enhances motivation, interest, and positive attitudes toward mathematics [55]–[57]. Contextualizing content through cultural artifacts brings concepts closer to students' daily experiences. Linking content to the culture of East Nusa Tenggara enhances learning interest. The combination of multimedia principles, problem based learning, and ethnomathematics explains the media's validity, acceptability, and impact on students' motivation, autonomy, and conceptual understanding in mathematics.

These findings are consistent with studies conducted in other developing countries, where mobile learning and interactive multimedia have been shown to enhance student engagement and conceptual understanding. However, unlike previous studies that primarily focus on general digital learning, this study integrates ethnomathematics with problem-based learning within a mobile learning environment. This integration represents a novel contribution, as it not only enhances cognitive engagement but also strengthens cultural relevance, which is rarely addressed in similar studies.

In relation to the research objectives, the findings indicate that the developed learning media meets the criteria of validity, practicality, and acceptability, while also demonstrating its potential to enhance students' interest in learning geometry. Practically, these findings suggest that teachers can utilize ethnomathematics-based mobile learning as an alternative instructional medium to create more engaging and contextually relevant mathematics learning. The integration of local cultural contexts also supports students in connecting abstract mathematical concepts with real-life experiences.

The present study is subject to several limitations. Firstly, the sample size was relatively small and limited to two schools, which may have an impact on the generalisability of the findings. Secondly, the study relied primarily on perception-based data without experimental comparison. It is recommended that future research employ a quasi-experimental design with a larger sample size in order to examine the effectiveness of the intervention to a greater degree of rigour.

This study's novelty lies in the integration of three key approaches—ethnomathematics, mobile learning, and problem-based learning—within an interactive multimedia environment using Articulate Storyline. Unlike previous studies that examined these components separately, this research provides a comprehensive instructional model that is both technology-enhanced and culturally responsive. The study's findings suggest that teachers could adopt mobile-based ethnomathematics as an alternative instructional strategy to enhance student engagement and understanding of context. Furthermore, this approach offers practical guidance for developing culturally relevant digital learning resources, particularly in underrepresented regions.

4. CONCLUSION

Based on the results of the development and limited-scale implementation phases, the ethnomathematics-based M-Learning media utilising Articulate Storyline in conjunction with a problem-based learning model can be considered valid, practical, and well accepted by users. The media demonstrate the potential to support students' understanding of geometric concepts and to enhance their interest in learning through interactive features and culturally contextualised content from East Nusa Tenggara. The integration of ethnomathematics, M-Learning, and problem-based learning offers a relevant and innovative approach to addressing the limitations of conventional mathematics instruction, particularly in promoting contextual and engaging learning experiences. However, the findings of this study are limited to a small sample from two schools; therefore, the generalizability of the results remains constrained. It is recommended that future research employ larger and more diverse samples and utilise more rigorous experimental designs, such as pretest–posttest approaches, in order to further examine the effectiveness of the developed media. Furthermore, future development may concentrate on extending content coverage, enriching problem-based learning scenarios, and incorporating a more extensive range of local cultural contexts, in addition to providing teacher training to support effective classroom implementation.

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AUTHOR CONTRIBUTIONS

Conceptualization, O.P.M.; Methodology, O.P.M.; Software, O.P.M.; Validation, O.P.M., K.S.J.; Formal Analysis, O.P.M.; Investigation, O.P.M.; Resources, O.P.M.; Data Curation, O.P.M.; Writing – Original Draft Preparation, O.P.M.; Writing – Review & Editing, O.P.M.; Visualization, O.P.M.; Supervision, K.S.J.; Project Administration, O.P.M.; Funding Acquisition, K.S.J.

INFORMED CONSENT STATEMENT

Informed consent was obtained from all participants in this study. Prior to participating, students and teachers were given a clear explanation of the study's objectives, procedures, potential benefits, and voluntary nature. Permission was also obtained from the participating schools. All data were collected anonymously and used solely for research purposes.

CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funding sponsor did not play a role in designing the study, collecting or analyzing data, writing the manuscript, or deciding to publish the results.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

Not applicable.

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