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INTEGRATING ETHNOMATHEMATICS AND DIGITAL COMICS: A CULTURALLY RESPONSIVE APPROACH TO ENHANCING NUMERACY LITERACY IN GEOMETRY

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ABSTRACT

Previous studies on digital media and ethnomathematics have rarely combined both in a unified, culturally responsive instructional tool. This study explores the development and evaluation of a digital mathematics comic media that integrates Acehese Kasab cloth patterns to enhance students' numeracy literacy in geometry. Drawing on ethnomathematics and multimedia learning theories, the media was designed to contextualize geometry through culturally meaningful visual narratives. A mixed-methods research and development approach was implemented, involving iterative expert validation, product refinement, and field trials in junior high schools across Aceh, Indonesia. Six expert reviewers assessed the media in terms of content, language, and usability, while thirty students participated in classroom trials. Results indicated substantial improvement in numeracy literacy, with a large effect size observed in student performance. Teachers and learners reported high levels of engagement, clarity, and cultural relevance. The findings support the effectiveness of integrating local heritage into digital learning tools as a means of fostering inclusive and meaningful mathematics instruction. This study offers a replicable model for educators and curriculum designers, while recommending future research through experimental and longitudinal designs to examine sustained outcomes.

KEYWORDS: Ethnomathematic, Digital Comic, Geometry; Numeracy Literacy.

1. INTRODUCTION

In the era of 21st-century learning, numeracy literacy has emerged as a core competency essential for student success across academic and real-world contexts (Aini et al., 2024). It goes beyond simple computation, encompassing the ability to apply mathematical reasoning in everyday situations, interpret quantitative data, and make informed decisions. Yet, despite its centrality in educational policy frameworks, students in many developing regions—including Indonesia—continue to perform below international standards in numeracy, particularly in geometry-related domains (Guo et al., 2019). This persistent gap is evident in national assessments such as the Asesmen Kompetensi Minimum (AKM), which reveal that a substantial proportion of junior high school students demonstrate only basic understanding in spatial and geometric reasoning.

One contributing factor to this underperformance is the lack of engaging and contextualized learning media. Traditional mathematics instruction often relies on abstract symbols and decontextualized problem sets, which fail to connect with students' lived experiences (Al-Abdullatif, 2022). In regions with rich cultural traditions, this disconnect becomes even more pronounced, as learning remains detached from local wisdom and social realities. Scholars in mathematics education have thus advocated for culturally responsive pedagogies—approaches that integrate indigenous knowledge and cultural practices to enhance relevance and deepen understanding (Cabrera-Solano et al., 2021).

A growing body of research highlights the potential of ethnomathematics, which situates mathematical learning within the context of local culture and artifacts (Kaaronen et al., 2024). Studies have shown that traditional textiles, crafts, and architecture often encode geometric principles such as symmetry, transformation, and patterning (Lu et al., 2021). One such cultural artifact is the Kasab cloth of Aceh, known for its intricate woven patterns and symbolic motifs. These features offer a unique opportunity to contextualize geometry instruction in a way that is both culturally meaningful and mathematically rich.

Simultaneously, the rapid advancement of digital technology in education opens new possibilities for enhancing student engagement. Digital comics, in particular, have gained attention as an innovative medium that combines narrative, visuals, and interactivity to support conceptual learning (Lee et al., 2023). Comics offer a storytelling format that aligns well with students' media consumption habits, providing a

bridge between entertainment and education. However, while comics and ethnomathematics have each been explored independently in prior studies, there is a lack of research examining their integration within a single digital learning tool.

To address this gap, the present study aimed to develop and evaluate a digital mathematics comic media based on the cultural geometry of Acehnese Kasab cloth, with the goal of improving junior high school students' numeracy literacy (Waluya et al., 2024). The media was designed not only to support mathematical understanding but also to promote cultural appreciation and engagement. Through a mixed-methods research and development approach, the study investigated the feasibility, validity, and effectiveness of the media from both expert and user perspectives.

This study contributes to the literature by offering a novel model of culturally embedded, digitally delivered mathematics instruction. It provides empirical evidence for the pedagogical value of integrating ethnomathematics into interactive learning formats, and it offers practical insights for educators and policymakers seeking to enrich STEM education through local culture and technological innovation.

2. LITERATURE REVIEW

2.1 Numeracy Literacy in Contemporary Mathematics Education

Numeracy literacy has evolved beyond simple arithmetic proficiency to encompass the ability to interpret, apply, and communicate mathematical information in diverse, real-life contexts (Kusdiyanti et al., 2024). It is now recognized as a core component of 21st-century skills essential for global citizenship and academic success (Santia & Handayani, 2023). In Indonesia, the implementation of the AKM seeks to measure these competencies. However, large-scale assessments show that students, particularly at the junior high school level, continue to perform poorly in geometry-based tasks involving spatial reasoning, symmetry, and transformation.

This gap highlights the inadequacy of conventional instructional methods in engaging students and promoting higher-order mathematical thinking. Geometry, in particular, remains abstract and difficult to visualize for many learners due to its traditional presentation in symbolic and decontextualized forms (Jagtap & Karniadakis, 2020). As a result, researchers and practitioners are increasingly advocating for contextualized learning approaches that ground abstract content in students' everyday and cultural experiences.

2.2 Ethnomathematics and Cultural Integration in Learning

Ethnomathematics, introduced by E. Zuliana et al. (Zuliana et al., 2023), provides a theoretical lens through which mathematics is viewed as a product of cultural practices (Muzaki et al., 2022). It proposes that mathematical ideas are embedded in artifacts, language, rituals, and craftsmanship. In recent years, the integration of local cultural elements into mathematics education has shown promise in improving student engagement, motivation, and conceptual understanding (Jeong, 2020). In the Indonesian context, traditional textiles such as batik, ulos, and tenun have been analyzed for their geometric structures and applied as ethnomathematical tools in the classroom.

The Kasab cloth of Aceh, with its intricate patterns and symmetrical designs, is rich in geometric properties that align with formal school mathematics. Despite its potential, this cultural artifact remains underutilized in educational settings. Previous efforts to integrate cultural materials have rarely gone beyond printed worksheets or thematic storytelling, lacking technological innovation or rigorous instructional design.

2.3 Comics and Digital Media in Mathematics Instruction

Digital comics represent a dynamic and increasingly relevant instructional format (Rina et al., 2020). They combine visual storytelling, dialogic elements, and narrative progression—offering a multimodal learning experience suited for digital-native students (Swandi et al., 2020). In mathematics education, digital comics have been used to introduce topics such as arithmetic, algebra, and geometry in a way that reduces anxiety and increases conceptual clarity.

The narrative structure inherent in comics supports sequential information processing, while the visuals aid in reducing cognitive load (Aggleton, 2019). However, most comic-based interventions in mathematics are generic in theme and lack local cultural relevance. Moreover, few studies have integrated comics with ethnomathematics to create culturally meaningful and pedagogically robust learning tools.

Despite growing interest in both ethnomathematics and digital comics as instructional tools, few studies have systematically integrated these two domains in a coherent learning design (Aladin et al., 2023). This study addresses that gap by combining cultural geometry with narrative-based digital comics, contributing to the development of

culturally responsive mathematics instruction in a digital age.

3.3. THEORETICAL FRAMEWORK

This research is grounded in two interrelated theoretical perspectives: Ethnomathematics Theory and Multimedia Learning Theory, both of which inform the design and evaluation of the digital mathematics comic media.

3.1 Ethnomathematics Theory

Ethnomathematics views mathematics not as a culturally neutral discipline, but as a body of knowledge shaped by human practices across different societies (Dewantara et al., 2023). This theory emphasizes the sociocultural context of mathematical reasoning, encouraging educators to draw upon traditional artifacts, spatial arrangements, and patterning practices to introduce formal concepts. In this study, Acehnese Kasab cloth—with its symmetrical motifs and woven geometry—serves as a culturally embedded foundation for teaching transformation and symmetry within geometry.

Research suggests that integrating students' cultural knowledge into mathematics learning enhances comprehension and retention by lowering cognitive barriers and strengthening relevance (Umbara & Suryadi, 2019). Ethnomathematics also fosters identity affirmation and inclusivity, particularly important in multicultural and postcolonial education systems such as Indonesia's.

3.2 Multimedia Learning Theory

Complementing the cultural dimension is Mayer's (2009) Cognitive Theory of Multimedia Learning, which posits that students learn more effectively from well-structured combinations of text, images, and audio than from text alone. The theory is underpinned by principles of dual-channel processing, limited capacity, and active learning. When learners are presented with information through both visual and verbal channels, they are more likely to construct meaningful mental representations.

Digital comics embody these principles by integrating narrative structure, characters, speech bubbles, and symbolic visuals (Terlouw et al., 2020). In this study, multimedia design principles were applied to ensure coherence, segmenting, signaling, and redundancy reduction within the digital comic format (Habiddin et al., 2022). The aim was to reduce cognitive load while maintaining high learner engagement.

Together, these two theoretical perspectives guided the design, development, and evaluation of the learning media within a structured research and

development (R&D) framework [23]. Ethnomathematics theory informed the cultural content and mathematical focus, while multimedia theory shaped the visual and instructional design of the digital comic product.

4. CONCEPTUAL FRAMEWORK

The following is a conceptual framework flowchart illustrating the relationships between the key elements of this study. The integration of Acehnes Kasab cloth (ethnomathematics) and digital comic media converges in the development stage (Damopolii *et al.*, 2021). Through expert validation and product trials, the feasibility and effectiveness of the media are assessed (Olaghere *et al.*, 2021). The final outcome is an improvement in students' numeracy literacy, particularly in geometry.

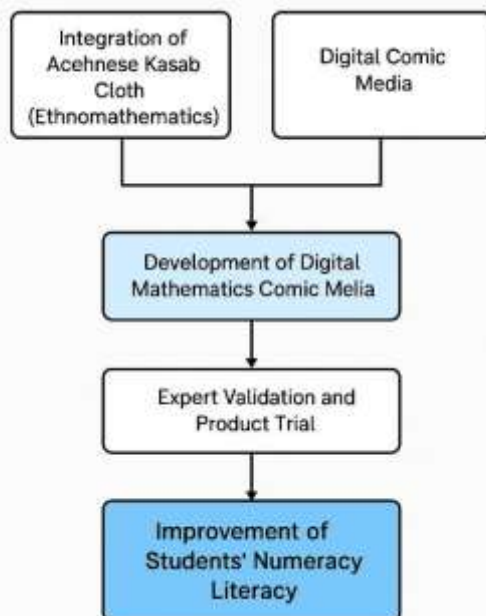


Figure 1. Conceptual Framework: Integration of Culture and Digital Media to Improve Numeracy Literacy

5. METHODOLOGY

5.1 Research Design

This study employed a Research and Development (R&D) design based on the Borg and Gall (2003) model, incorporating both qualitative and quantitative approaches (Johnson, 2014). The aim was to develop, validate, and evaluate a digital mathematics comic media that integrates elements of Acehnes culture to improve students' numeracy literacy. The model includes ten steps, of which eight were applied in this study: (1) data collection, (2) planning, (3) product design, (4) initial validation, (5)

product revision, (6) limited trial, (7) field testing, and (8) final product refinement.

This model was chosen due to its iterative and systematic nature, enabling ongoing feedback from multiple stakeholders. It aligns with design-based research principles in educational technology development, which emphasize contextual relevance, refinement, and empirical grounding.

5.2 Participants

Participants were selected purposively from five junior high schools in Aceh Province, Indonesia: SMPN 4 Peusangan, SMPN 1 Peukan Baro, MTsN 2 North Aceh, MTsN 2 Pidie Jaya, and SMPN 14 Takengon. These schools were chosen based on their willingness to collaborate and their curricular needs in geometry instruction.

The study involved:

- five mathematics teachers, one from each school, contributing to the needs analysis and media evaluation;
- Six expert validators, including two mathematics education specialists, two digital media experts, and two linguists;
- thirty eighth-grade students from one of the schools, participating in the trial phase and completing pre-post numeracy assessments.

5.3 Instruments

This study employed three primary instruments to support the development and evaluation of the digital comic media. The expert validation sheet assessed six key aspects—content, presentation, language, ethnomathematical integration, media clarity, and usability—using a 5-point Likert scale, with scores converted into percentages for feasibility analysis.

To measure learning outcomes, a numeracy literacy test consisting of ten geometry-based items was used. The items, adapted from the national AKM framework, focused on transformation, symmetry, and patterning, and were validated by two mathematics experts to ensure alignment with the curriculum.

In addition, perception questionnaires were distributed to both students and teachers, using a 4-point semantic differential scale to evaluate clarity, engagement, visual appeal, and cultural relevance of the media.

All instruments were reviewed for content validity and revised based on expert input. A pilot test with 15 students was conducted to ensure clarity and reliability before the instruments were used in the main study.

5.4 Product Development Procedure

The development process began with identifying students' needs and common learning difficulties in geometry. Based on this, a digital comic was designed using MediBang and Canva software. The comic narrative was structured around Acehese cultural elements, specifically Kasab cloth motifs, integrated with geometry learning tasks.

The product went through two validation cycles with input from experts. After each cycle, revisions were made to enhance clarity, cultural accuracy, and mathematical rigor. Final implementation involved distribution to students in digital format (PDF/Android-compatible), followed by trial and feedback.

5.5 Data Collection and Analysis

Data collection in this study was conducted in three main stages. The first stage involved a needs analysis, carried out through interviews with mathematics teachers and curriculum mapping to identify instructional challenges and ensure alignment with learning objectives. The second stage focused on expert validation of the comic media by specialists in mathematics education, language, and digital media, using structured validation instruments. Finally, the third stage included field implementation, where the revised digital comic was tested in a classroom setting with students and teachers providing feedback through perception questionnaires to evaluate its effectiveness and usability.

Quantitative data from validation scores and pre-post numeracy tests were analyzed using descriptive statistics (mean, percentage) and effect size calculation (Bauer et al., 2021). The gain in student performance was evaluated using Cohen's d :

$$\text{Cohen's } d = \frac{M_{\text{post}} - M_{\text{pre}}}{SD_{\text{gain}}}$$

Qualitative data from expert comments and open-ended responses were analyzed using thematic analysis, following Braun and Clarke's (2006) six-phase method. Themes were inductively coded to identify recurring patterns and suggestions for product refinement.

6. RESULTS

6.1 Needs Analysis and Contextual Mapping

Interviews and surveys with educators from five schools revealed that students exhibited low engagement with conventional geometry instruction and lacked cultural contextualization in learning materials. The Kasab cloth, characterized by

symmetrical and repetitive patterns, was identified as a culturally rich medium to enhance students' understanding of geometric concepts.

6.2 Initial Product Design

The media was structured into a digital comic format with culturally inspired storylines, visual narratives, and geometric problems embedded within motifs of Kasab cloth. Visual design considerations included traditional patterns, Acehese attire, and story-driven problem scenarios. The prototype featured a cover, foreword, content modules, and post-activity reflections.

6.3 Expert Validation and Revisions

6.3.1 Material Expert Validation

Material validation was conducted in two phases. Table 1 summarizes the results.

Table 1. Material Expert Validation Scores

Validation Aspect	Phase I (%)	Phase II (%)
Content Appropriateness	67.5	77.5
Presentation Feasibility	62.5	77.5
Language Feasibility	62.5	77.5
Ethnomathematical Content	37.5	72.5
Average	57.5	76.25

The initial low score in ethnomathematical content (37.5%) highlighted a gap in aligning traditional patterns with mathematical theory. After revision—including integration of HOTS-based geometry problems using Kasab motifs—scores improved across all dimensions, indicating the product's cultural and pedagogical feasibility.

6.3.2 Language Expert Validation

Language validation (see Table 2) showed a marked improvement from Phase I (52%) to Phase II (97.5%). Weaknesses in dialogue clarity and communicative tone were addressed by simplifying language and increasing narrative coherence.

Table 2. Language Expert Validation Scores

Validation Aspect	Phase I (%)	Phase II (%)
Clarity of Information	75	100
Readability	62.5	75
Efficiency of Language	50	75
Engaging Dialogue	50	87.5
Communicative Language	37.5	87.5
Aesthetic Appeal	37.5	62.5
Average	52	97.5

6.3.3 Media Design Validation

Initial feedback emphasized design shortcomings, particularly in layout, font choice, and clarity of components. Adjustments included standard comic

font usage and redesigning the front cover and navigation layout. The overall feasibility score improved from 47.9% to 83%.

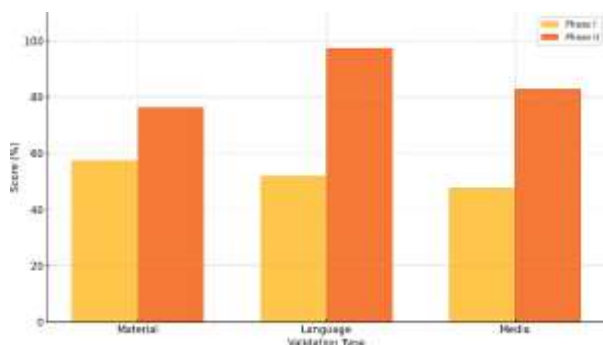


Figure 2. Comparison of Expert Validation Results Between Phase I and Phase II

As illustrated in Figure 1, validation scores across all domains showed substantial improvement from Phase I to Phase II. Material validation increased by 18.75 percentage points, while language validation rose dramatically by 45.5 percentage points. Media validation also experienced a considerable enhancement of 35.1 percentage points. These improvements reflect the effectiveness of the revisions made based on expert feedback and highlight the iterative design process as a key factor in media development success.

6.4 Educator and Student Trial Outcomes

Post-validation trials were conducted to assess product effectiveness on learning engagement and numeracy literacy. The digital comic was piloted in one of the five schools with 30 students, while educator feedback was gathered from five teacher representatives.

Table 3. Educator and Learner Response

Respondents	Total Score (F)	Max Score (N)	Percentage (%)	Category
Teachers	124	140	88.6	Very Good
Students	717	840	85.4	Very Good

6.5 Statistical Evaluation of Effectiveness

To assess the media’s impact, pre- and post-use performance data (numeracy literacy tasks) from a sample of 30 students were analyzed. The average improvement score was

- mean pre-test: 61.2
- mean post-test: 78.9
- mean gain: 17.7
- standard deviation (gain): 10.8
- effect size (cohen’s d): 1.64 → large effect

The large effect size indicates that the digital comic had a substantial impact on improving students’

numeracy skills, consistent with prior findings on culturally contextualized learning.

6.6 Critical Reflection

Despite promising results, initial expert assessments underscored challenges in effectively translating ethnomathematics into coherent instructional content. The low early scores (e.g., 37.5% in ethnomathematical content, 47.9% in media presentation) reflect the complexity of balancing cultural fidelity with pedagogical clarity. These findings reinforce the importance of iterative design grounded in interdisciplinary collaboration between educators, linguists, and cultural scholars.

Additionally, while feedback from educators and students was overwhelmingly positive, future studies may include control groups or longitudinal tracking to validate long-term retention and transferability of skills.

7. DISCUSSION

This study directly addressed the research question by demonstrating that culturally embedded digital comics significantly enhance junior high school students’ numeracy literacy (Istiq’faroh & Mustadi, 2020). This was evidenced by a substantial improvement in student performance (mean gain = 17.7; Cohen’s d = 1.64) and by marked increases in expert validation scores across all domains—material (from 57.5% to 76.25%), language (52% to 97.5%), and media design (47.9% to 83%).

7.1 Cultural Integration Enhances Cognitive Engagement

The incorporation of Acehese Kasab cloth into mathematics comic media reflects a deliberate attempt to contextualize abstract geometry concepts within culturally familiar settings. This strategy aligns with the theoretical framework of ethnomathematics, which posits that mathematical ideas are not culturally neutral but embedded within social practices and artifacts (Nahdi et al., 2020). In this study, Kasab motifs—known for their symmetrical, repetitive patterns—served as the foundation for teaching transformations and spatial reasoning, key components of geometry.

Students responded positively to this integration. Their interaction with familiar cultural symbols—presented in a modern, digital narrative format—appears to have enhanced both their cognitive processing and affective engagement. This aligns with findings, who reported improved literacy outcomes when local cultural contexts were embedded into mathematical tasks (Gal et al., 2020).

By recognizing mathematical principles in familiar cultural patterns, students were able to interpret and analyze content with greater personal relevance and reduced abstraction.

Notably, the validation scores for ethnomathematical content increased from 37.5% in Phase I to 72.5% in Phase II, indicating that expert reviewers perceived a significant improvement in how well cultural integration was executed. This underscores the importance of iterative refinement when developing culturally grounded materials (Lynch et al., 2023). The increase suggests not only better alignment with learning objectives but also a more authentic representation of cultural meaning within the learning media.

Cognitive engagement is further reflected in students' numeracy performance. The large effect size ($d = 1.64$) recorded in pre-post tests shows that cultural contextualization may serve as a cognitive scaffold, helping students bridge prior knowledge with new mathematical concepts (Murphy et al., 2022). This echoes the findings, who emphasized the role of contextual familiarity in enhancing mathematical literacy, especially among students with lower prior achievement.

Furthermore, the use of culturally embedded media supports affective learning dimensions such as identity affirmation and cultural validation. When students see their heritage reflected in learning materials, it fosters a sense of belonging and confidence. In the Acehnese context, where formal schooling often overlooks indigenous knowledge systems, this approach may contribute to a more inclusive and empowering learning environment. As suggested by J. Cuartas et al. (Cuartas et al., 2023), such affective factors are not peripheral but central to sustained academic engagement.

Finally, this integration serves a dual purpose: it reinforces curricular content while promoting cultural preservation. As education systems face growing pressure to deliver globally standardized outcomes, the inclusion of localized cultural elements ensures that indigenous knowledge is not lost. This study demonstrates that such integration is not only feasible but pedagogically beneficial. It encourages future efforts to frame mathematics as both a universal and culturally situated discipline.

7.2 Narrative-Based Digital Comics as Pedagogical Innovation

The use of narrative-based digital comics introduces a novel approach to mathematics instruction by merging storytelling, visual art, and technology (Buoye et al., 2020). Comics offer a multimodal platform where images, dialogues, and

structured sequences work synergistically to convey complex ideas in an accessible format. In the current study, the comic medium served not merely as a decorative tool but as a scaffolded instructional strategy designed to enhance understanding and retention of geometry concepts.

Digital comics provide a unique affordance: they present content sequentially, guiding learners through a coherent storyline while embedding mathematical tasks within real-life scenarios (Linardatos & Apostolou, 2023). This narrative structure promotes cognitive flow and minimizes cognitive load, a principle supported by T. Tong, H. Li et al. (Tong et al., 2019) cognitive theory of multimedia learning. By placing geometry tasks within culturally rich comic panels, learners are not only engaged but also anchored in contexts that are meaningful and interpretable.

The shift from static, text-heavy instructional materials to dynamic, story-driven digital comics represents an evolution in pedagogical practice (Yecies et al., 2020). Such media address the needs of digital-native learners who are accustomed to consuming information through interactive, visual platforms. The validation results in this study—particularly the 97.5% feasibility score from linguists and 83% from media experts—demonstrate the practicality and quality of this approach. These scores suggest that narrative coherence, visual design, and linguistic accessibility were well-implemented.

More importantly, the comic format allows for the humanization of mathematical content. Characters in the comics act as cultural and cognitive agents, modeling mathematical thinking, asking questions, and reflecting on cultural symbols such as Kasab cloth. This personal and relatable delivery enhances learners' emotional connection to the material, a dimension often overlooked in traditional STEM instruction. The emotional resonance found in well-designed educational comics has been recognized by M. Ebubedike et al. (Ebubedike et al., 2022) as a key factor in student motivation and persistence.

The flexibility of digital formats also plays a critical role in implementation. Unlike printed textbooks, digital comics can be disseminated easily across devices, enabling equitable access even in resource-constrained environments (Inyabri et al., 2021). This scalability makes them a viable solution for large-scale educational innovation, especially in culturally diverse and geographically dispersed regions like Indonesia. When designed with local relevance and pedagogical precision, such tools can close the gap between curriculum standards and actual classroom engagement.

Nevertheless, developing such media requires a multidisciplinary approach. In this study, collaboration among mathematics educators, cultural experts, illustrators, and language specialists ensured that the comic was not only engaging but also mathematically sound and culturally respectful (Mills et al., 2020). The success of the digital comic reinforces the idea that impactful learning innovations are born at the intersection of disciplines—and that narrative, culture, and digital design are powerful allies in education.

7.3 Iterative Design Driven by Multidimensional Validation

The iterative development process in this study was essential to refining the product's educational and cultural quality. Initial validation scores revealed key weaknesses, such as insufficient clarity in component layout, ineffective dialogue, and superficial ethnomathematical integration. These limitations, while expected in early prototypes, served as constructive inputs that guided targeted revisions (Idowu & Ogunnubi, 2023). The multidimensional validation process—incorporating expert feedback from material, language, and media perspectives—enabled a more holistic refinement of the digital comic media.

In the first phase of validation, the media scored below 60% across all dimensions, indicating significant room for improvement. For instance, the media design aspect was rated at only 47.9%, primarily due to issues in font selection, navigation structure, and visual appeal. Experts also criticized the comic's dialogue as being unclear or overly didactic. These findings echo those of S. Goswami et al. (Goswami et al., 2020), who emphasized the importance of usability and narrative fluency in digital mathematics games and comics.

The revised version of the product demonstrated considerable improvement. Validation scores increased to 83% for media, 76.25% for material, and 97.5% for language, reflecting the success of the revision process. This increase not only signifies the effectiveness of expert-driven design iteration but also validates the importance of domain-specific review. When feedback from linguists, media designers, and mathematicians is triangulated, the resulting product is more balanced, functional, and pedagogically sound.

This iterative approach underscores a critical principle in instructional design: that learning media should be treated as dynamic prototypes rather than static products. Each round of validation adds nuance and robustness to the final output. Such a model mirrors agile development processes in the tech

industry, where rapid feedback and adaptation are prioritized. As noted by S. Bhatnagar et al. (Bhatnagar et al., 2019), the most impactful educational technologies are those that evolve through continuous dialogue between design and implementation.

Another strength of this validation-driven development is its capacity to capture the multidimensionality of learning experiences. While many educational tools are evaluated solely on content accuracy or engagement, this study's framework considered six validation indicators per expert domain. These included content appropriateness, presentation, language use, communicative clarity, design aesthetics, and operational ease. Such comprehensive assessment ensures that the learning media is both cognitively and culturally viable.

Moreover, expert feedback provided specific, actionable suggestions. For example, material experts requested the inclusion of HOTS-based questions and stronger alignment between geometry tasks and Kasab patterns. Linguists recommended improving dialogue fluidity, while media experts emphasized the need for intuitive layout and visual coherence. The implementation of these suggestions not only improved validation scores but also enhanced user experience, as reflected in positive responses from students and teachers.

Finally, this iterative, feedback-oriented process cultivates a culture of reflective practice among educational developers. By embedding validation as a core design element rather than a post-hoc evaluation, the development process becomes more transparent, collaborative, and accountable. It exemplifies a model of educational innovation that is empirical, responsive, and respectful of both cultural context and instructional integrity.

7.4 Practical and Policy Implications

From a practical standpoint, this study introduces a replicable model for developing mathematics learning media that is both culturally rooted and technologically mediated. For regions rich in cultural diversity but lacking engaging instructional tools, such media can bridge gaps in curriculum relevance and student motivation. For policymakers, these findings underscore the importance of incorporating local wisdom into national education strategies, not as ornamentation but as core instructional substance.

7.5 Limitations and Directions for Future Research

While the findings are promising, this study had limitations. The absence of a control group restricts

causal inferences, and the implementation of the product in only one class for effectiveness testing limits generalizability. Future research should consider quasi-experimental or randomized controlled designs to strengthen empirical claims. Longitudinal studies are also needed to examine the retention of numeracy gains and to explore the role of cultural familiarity in enhancing mathematical reasoning over time.

8. CONCLUSION

This study developed and evaluated a culturally integrated digital comic media based on Acehese Kasab cloth to support numeracy literacy in geometry among junior high school students. The findings confirm that integrating local ethnomathematical elements with digital storytelling enhances student engagement and learning outcomes. Validation scores improved significantly across material, media, and linguistic domains, and the use of the comic resulted in a large effect size on students' numeracy performance. The research demonstrates that localized digital media can offer relevant and meaningful learning experiences while

preserving cultural identity. Despite limitations in design scope and implementation scale, the study offers a replicable instructional model for educators seeking to contextualize STEM education. Future research is encouraged to explore experimental and longitudinal designs to expand on these findings.

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10. CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this article.

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