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Research Article

DEVELOPMENT OF CULTURE-BASED AR-ASSISTED COMICS BOOK TO ENHANCE LEARNING MOTIVATION

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Abstract
The research aims to develop, validate, and evaluate *Bucomath*, a culture-based mathematics comic book integrated with Augmented Reality (AR), designed to provide a contextual, interactive, and culturally relevant learning experience. Using a ADDIE model, the study involved 37 ninth-grade students and collected data through expert validation sheets, teacher and student practicality questionnaires, classroom observations, pre–post motivation scales, and structural equation modeling using SmartPLS 4. The results indicate that Bucomath achieved very high validity (83.22%) in both content and design aspects, along with strong practicality ratings from teachers and students (88.22%). The effectiveness analysis revealed a substantial improvement in learning motivation, with an N-Gain score of 0.73 categorized as high, while PLS-SEM results showed that Engagement ($R^2 = 0.64$) significantly mediated the influence of Perceived Usefulness and Perceived Enjoyment on Learning Interest ($R^2 = 0.71$), with all path coefficients statistically significant ($p < 0.05$). These findings suggest that the combination of cultural narratives such as Jambi traditional architecture and batik geometry with AR-based 3D visualization successfully transforms abstract mathematical concepts into concrete and emotionally engaging learning experiences. In conclusion, Bucomath demonstrates that integrating local cultural identity with immersive AR technology has strong pedagogical potential to enhance students' intrinsic motivation, cognitive engagement, and positive attitudes toward mathematics. The implications of this study highlight that culturally responsive AR media can serve as a scalable and inclusive model for future digital learning innovations, supporting not only mathematical understanding but also cultural appreciation and identity-affirming education across diverse learning environments.

Keywords: Augmented Reality (AR), Culture-Based Mathematics Comics, Engagement, Learning Interest

INTRODUCTION

The decline in motivation and engagement in mathematics learning presents a significant challenge for Indonesia's education system, which aims to improve the quality of 21st-century education. Research indicates that students worldwide often view mathematics as abstract, challenging, and irrelevant, resulting in low engagement and limited academic success (Wang et al., 2022; Xia et al., 2022; Hossein-Mohand & Hossein-Mohand, 2023). The Programme for International Student Assessment (PISA) 2022 results illustrate this trend, with Indonesian students achieving an average score of 366 in mathematics, significantly lower than the OECD average of 472, positioning the country among the lowest in global numeracy performance (OECD, 2023; Bilad et al., 2024; Wijaya et al., 2024). Low achievement indicates both conceptual deficiencies and a lack of student engagement and interest in mathematics learning (Saglam & Goktenturk, 2024; Sandman et al., 2025). These conditions necessitate innovative pedagogical strategies that render mathematics more contextual, meaningful, and pertinent to students' real-life and cultural experiences (Cabero-Almenara et al., 2022; Boadu & Boateng, 2024).

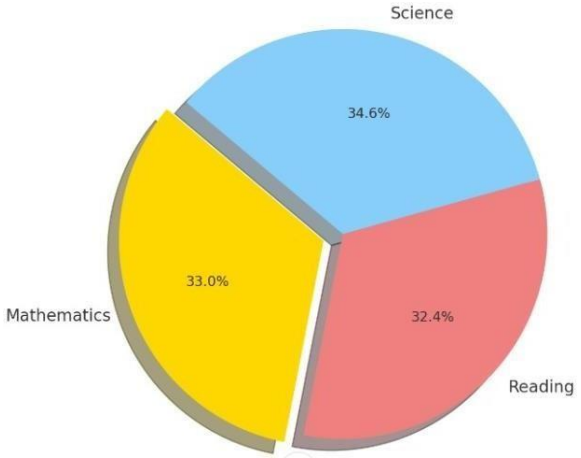


Figure 1. Indonesian students' achievement in science, mathematics, and reading (PISA 2022).

The achievement distribution of Indonesian students is depicted in Figure 1, where mathematics (33.0%) is marginally higher than reading (32.4%) and slightly lower than science (34.6%). This discrepancy highlights the need for more contextualized and interesting teaching strategies by illuminating students' poor conceptual understanding and decreased motivation to learn mathematics in comparison to other subjects. The role of learning motivation is crucial in influencing academic success and persistence in STEM disciplines. Research shows a positive correlation between strong intrinsic motivation, persistence, and higher academic achievement (Papageorgiou et al., 2025). Students who perceive mathematics as relevant to their social and cultural contexts show increased enthusiasm and persistence in problem-solving (Wang et al., 2022; Schukajlow et al., 2023). Therefore, pedagogical methods that integrate technological innovation with cultural relevance are crucial for enhancing student motivation and engagement in mathematics education (Rizal et al., 2021; Hamzah et al., 2022).

Various strategies have been developed to make mathematics learning more engaging and interactive. One effective approach is the use of educational comics, which combine storytelling, visuals, and humor to simplify abstract concepts into concrete representations (Daulay, 2017; Kurniawati et al., 2017; Lepore, 2024). Empirical evidence shows that comic-based learning improves conceptual understanding and learning motivation (Apostolou & Linardatos, 2023). However, most math comics remain static and lack interactive features that can encourage deeper cognitive engagement.

Augmented Reality (AR) has emerged as a transformative educational technology, enabling students to visualize three-dimensional mathematical representations in real-world contexts (del Cerro Velázquez & Morales Méndez, 2021; Zuo et al., 2025). Studies indicate that augmented reality (AR) learning improves spatial reasoning, conceptual comprehension, and learner motivation (Bulut & Borromeo Ferri, 2023a; Koparan et al., 2023). Many AR implementations prioritize technical novelty, often overlooking the incorporation of cultural and social contexts (Dewi & Putri, 2024). Incorporating cultural dimensions into augmented reality learning experiences may enhance relevance and meaning, thereby improving student engagement.

This research aims to develop an innovative learning medium, called Bucomath (Culture-Based Comic Math Book with Augmented Reality), to address the identified gaps. This research aims to develop, validate, and assess the effectiveness of Bucomath in enhancing students' learning motivation. This model combines three fundamental dimensions: narrative storytelling through comics, digital interactivity through augmented reality, and cultural contextualization through Jambi's local heritage. This research provides both theoretical and practical contributions. This approach theoretically extends the concept of culturally responsive pedagogy by combining interactive technology and visual narratives to enhance motivation in mathematics (Gay, 2010). This framework offers a foundation for educators and curriculum developers to create evidence-based, contextual, and culturally relevant digital learning media. The incorporation of Jambi cultural elements, including traditional Kajang Lako architecture and geometric batik patterns, illustrates the potential of local heritage to be transformed into digital innovations that enhance learning motivation and strengthen cultural identity.

RESEARCH METHOD

This study employed a Research and Development (R&D) methodology to create a valid, practical, and effective educational resource known as Bucomath a culturally based Comic Math Book enhanced with Augmented Reality (AR). The five systematic stages of the ADDIE model, analysis, design, development, implementation, and evaluation, were integrated into the development framework (Branch, 2009). Due to its comprehensive and iterative process, which ensures a balanced integration of pedagogical, cultural, and technological aspects, this model was chosen. In addition to creating a new product, this R&D strategy also aimed to test its educational feasibility in enhancing students' motivation to learn mathematics.

This research was conducted in the 2024 academic year at MTs Laboratorium UIN STS Jambi, Indonesia. Thirty-seven ninth-grade students representing high, medium, and low academic ability levels were selected using purposive sampling, along with a mathematics teacher. The research involved 37 ninth-grade students at MTs Laboratorium UIN STS Jambi, selected through purposive sampling based on students' readiness, device availability, and school collaboration. Data were collected using expert validation sheets, teacher and student practicality questionnaires, pre–post learning motivation scales, observation sheets, and semi-structured interviews. Expert validation assessed content and design accuracy, while practicality instruments evaluated usability, attractiveness, and clarity. The learning motivation scale measured changes before and after the intervention. Data collection was conducted through validation, small- and large-scale trials, questionnaire administration, classroom observations, and interviews. The students participated in small- and large-scale classroom trials, while the teacher participated in validation and practical testing. The website was selected due to its suitability for testing culturally enriched mathematics learning materials, its accessibility, and its willingness to collaborate with others.

An expert validation sheet, practicality questionnaires for teachers and students, pre- and post-test motivation scales, and observation and interview protocols were used to collect data. The two main areas of expert validation were design validity, which evaluated layout, graphics, and AR integration, and content validity, which assessed the appropriateness and accuracy of the mathematical content. Teacher and student opinions regarding usability, clarity, and appeal were assessed using a practicality questionnaire. Learning interest was measured before and after using Bucomath using a student motivation tool modified (Nieveen, 2010). Qualitative information from observations and interviews provided mutually reinforcing contextual insights, and all quantitative data were rated on a five-point Likert scale.

The Bucomath development process was iterative and integrated the five stages of the ADDIE model. Through teacher interviews and classroom observations, a needs assessment was conducted during the analysis phase. Findings indicated that traditional teaching methods and a lack of contextual linkage between mathematical ideas and students' cultural contexts were the main causes of low student motivation. Based on these results, the design phase included the creation of a prototype that integrated traditional ornaments, geometric batik motifs, and the Kajang Leko traditional house into the mathematical topics of spatial geometry and plane figures. Canva was used to create comics, and AssemblrEdu was used to create augmented reality components that enabled 3D visualization on smartphones.

The prototype was validated by experts during the development phase to evaluate its accuracy, aesthetics, and technological functionality. Based on expert feedback, the media was updated to enhance visual interactivity, narrative flow, and content coherence. The implementation phase involved piloting the updated Bucomath with small and large groups of students. Teachers were given a brief introduction to the use of AR features and the media's integration into lesson plans. Finally, the evaluation phase measured the validity, usability, and overall efficacy of Bucomath as a learning tool through formative evaluations at each stage and summative evaluations after implementation.

Analyzing data involved combining qualitative and quantitative techniques. To calculate percentage scores, quantitative data from practicality and validation questionnaires were analyzed using descriptive statistics. These scores were then classified as very valid/practical (81–100%), valid/practical (61–80%), fairly valid/practical (41–60%), and so on (Nieveen, 2010; Riduwan, 2015). By using normalized gain (N-Gain) analysis to compare students' motivation scores before and after the intervention, the efficacy of Bucomath was ascertained using the following equation:

$$g = \frac{Spost - Spre}{Smax - Spre} \ldots (1)$$

According to Rizqiyani, Anriani, and Pamungkas (2022), the gain values were interpreted as low ($g < 0.3$), moderate ($0.3 \leq g \leq 0.7$), and high ($g > 0.7$). In order to describe students' behavioral and affective engagement during the learning process and to triangulate quantitative results, qualitative data from classroom observations and interviews were subjected to thematic analysis.

RESULTS AND DISCUSSION

The results of this research and development study present the empirical findings on the validity, practicality, and effectiveness of *Bucomath*, a culture-based *Comics Mathematics Book* supported by Augmented Reality (AR). Data were obtained from expert validation, teacher and student practicality assessments, and pre- and post-test motivation questionnaires. The following tables summarize the results of each aspect.

Table 1. Expert Validation of Bucomath Media

Aspect	Indicators	Mean Score (%)	Category
Content validity	Accuracy of mathematical material; clarity of objectives; alignment with curriculum	82.34	Very valid
Design validity	Layout, color harmony, readability, integration of AR, and visual appeal	84.11	Very valid
Average		83.22	Very valid

The validation results (Table 1) indicate that *Bucomath* achieved a very high level of validity (M = 83.22%), demonstrating that the content, visual presentation, and AR integration met pedagogical and technical standards. These results are consistent with Nieveen's criteria, where scores above 80% indicate products that are feasible for classroom implementation (Nieveen, 2010).

After expert revisions, small-scale and large-scale practicality trials were conducted to evaluate usability from teachers' and students' perspectives. Teachers assessed ease of use, classroom integration, and instructional clarity, while students rated attractiveness, accessibility, and engagement.

Table 2. Practicality Assessment Results

Respondent	Mean Score (%)	Category
Teacher practicality	92.32	Very practical
Student practicality	84.13	Very practical
Average	88.22	Very practical

As shown in Table 2, both teachers and students rated the media as "very practical," with an overall mean of 88.22%. Teachers emphasized that the AR feature reduced their workload in explaining spatial concepts, while students reported that the comics' humor and visuals made learning more

enjoyable. The effectiveness of *Bucomath* was assessed through pre-test and post-test motivation questionnaires, analyzed using normalized gain (*N-Gain*) scores.

Table 3. N-Gain Score of Students' Learning Motivation

Variable	Mean Pre-Test	Mean Post-Test	N-Gain	Category
Learning motivation	63.21	85.47	0.73	High

As presented in Table 3, the N-Gain value of 0.73 falls within the "high" category Hake (1998), indicating a substantial increase in students' learning motivation after using *Bucomath*. This improvement supports the findings of , who observed that AR-based learning Kovalenko et al. (2021); Meilindawati et al. (2023) media enhance emotional engagement and sustained attention. Overall, the quantitative findings confirm that *Bucomath* fulfills all three quality criteria of an educational product, validity (83.22%), practicality (88.22%), and effectiveness (N-Gain = 0.73). These results demonstrate that the developed media is pedagogically sound, technically feasible, and effective in enhancing students' motivation in mathematics learning. Collectively, the validation, practicality, and effectiveness data confirmed that *Bucomath* met all three quality dimensions validity, practicality, and effectivenesssuggesting that it is both pedagogically robust and technologically reliable for mathematics instruction.

According to the research and development study's findings, students' interest and motivation in learning mathematics were greatly increased when the culturally relevant Comics Mathematics Book was combined with Augmented Reality (AR). The AR features helped students visualize abstract mathematical concepts more concretely, which improved their conceptual understanding and decreased learning anxiety. As a result, students became more enthusiastic and engaged. Students' views of mathematics were successfully changed from one of difficulty and abstraction to one of context, relevance, and enjoyment through the incorporation of Jambi's local cultural elements. Higher learning motivation and participation resulted from this cultural contextualization, which improved the link between mathematics and students' everyday experiences. In addition, students stated that, in contrast to traditional teaching techniques, the AR-supported comics produced a more engaging and interactive learning environment that promoted cooperation and sustained attention. The creation of Bucomath using the ADDIE model showed that combining interactive augmented reality technology, visual storytelling, and cultural context could successfully connect pedagogical innovation with students' affective and cognitive engagement in mathematics education.

Analysis Stage

The analysis stage of the ADDIE development model served as the foundational phase for identifying the pedagogical challenges and motivational issues present in mathematics learning. Field observations and interviews with mathematics teachers revealed that instructional practices in the research context were primarily teacher-centered, emphasizing procedural mastery rather than conceptual understanding. Students tended to focus on rote memorization of formulas without fully grasping their underlying meanings or real-world relevance. This finding corroborates previous studies, such as those by Xu et al. (2023), which highlighted that when mathematics is presented in abstract and decontextualized forms, learners experience decreased engagement and increased anxiety toward the subject.

The needs analysis also showed that the limited integration of technology and cultural context in the classroom contributed to students' low motivation. Teachers often relied on static textbooks and conventional teaching aids, which were insufficient to address diverse learning preferences or to visualize abstract mathematical concepts effectively. These conditions align with, who found that low student motivation often stems from a lack of contextual and interactive learning resources. Furthermore, the local curriculum's emphasis on achieving standardized outcomes sometimes overlooked the importance of culturally relevant pedagogy, which is essential in promoting meaningful learning experiences in heterogeneous classrooms.

Based on these findings, it was determined that students required a learning medium that could connect mathematical abstraction with cultural familiarity and technological interactivity. This realization became the pedagogical rationale for developing *Bucomath*, a *Comics Mathematics Book* that integrates Jambi cultural elements with Augmented Reality (AR). The design was envisioned as a response to the motivational and contextual gaps identified during the analysis phase. The use of comic narratives aimed

to reduce students' affective barriers and anxiety, while the integration of AR technology sought to transform abstract geometry into tangible experiences. The incorporation of local culture further strengthened emotional engagement by allowing students to see mathematics embedded in their own traditions and environment, thus fostering a sense of identity and pride in learning.

In summary, the analysis stage established the empirical and theoretical foundation for developing *Bucomath* as a medium that addresses both motivational and cognitive dimensions of learning. By identifying the need for contextualized, visual, and interactive learning experiences, this stage provided a clear pedagogical justification for combining culture-based narratives, mathematical visualization, and AR interactivity in subsequent stages of development.

Design Stage

The design stage represented the conceptual core of the *Bucomath* development process. At this stage, theoretical insights from culturally responsive pedagogy and multimedia learning theory were translated into design principles that guided the creation of a digital comic-based mathematics learning medium supported by Augmented Reality (AR) (Gay, 2010). The design emphasized three pedagogical dimensions: narrative contextualization, cultural integration, and digital interactivity. These elements were strategically aligned to respond to the motivational needs and cognitive barriers identified during the analysis phase.

The narrative component of *Bucomath* was developed through comic storytelling that features relatable characters and authentic social situations drawn from Jambi's cultural context. Each episode introduced a mathematical concept embedded in daily cultural practices such as calculating proportions in *Kajang Lako* traditional house construction, identifying geometric patterns in batik motifs, or analyzing symmetry in traditional ornaments. This design strategy aimed to transform mathematics from an abstract subject into an engaging story that connects learners' cultural experiences with mathematical reasoning. Such narrative contextualization resonates with the findings of Fahreza et al. (2022), who demonstrated that digital comics foster affective engagement and conceptual understanding by humanizing mathematical ideas.

The cultural integration was carefully planned to ensure both authenticity and educational relevance (Eliyanti et al., 2024). Local experts were consulted to validate cultural representations, preventing misinterpretation or superficial use of symbols. Embedding Jambi's tangible and intangible heritage within mathematical tasks enabled students to perceive mathematics as a living practice rooted in their environment. This approach aligns with ethnomathematical perspectives, which argue that cultural contextualization enriches meaning-making and supports identity-affirming learning experiences.

The technological design focused on leveraging AR to enhance visualization and interactivity. Through the AssemblrEdu platform, students could scan specific comic panels to access 3-D models illustrating geometric relationships, surface area, and volume. AR objects were synchronized with the storyline so that learners could manipulate visual models while following the plot, thereby merging cognitive and emotional engagement. Previous studies by Gusteti et al. (2023) confirmed that AR-enhanced visualization reduces cognitive load and supports spatial reasoning in mathematics. Accordingly, integrating AR within a culturally grounded comic provided a dual pathway for learning, *visual immersion* and *contextual relevance*.

Pedagogically, the design of *Bucomath* adhered to constructivist principles by positioning learners as active meaning-makers. Tasks and reflection prompts embedded in the comic panels encouraged inquiry, prediction, and problem-solving rather than passive consumption of information. Color harmony, typography, and panel sequencing were optimized using Canva to maintain readability and aesthetic balance, which according to Bulut & Borromeo Ferri (2023) is critical for sustaining cognitive engagement in visual media.

Overall, the design stage transformed theoretical frameworks into concrete visual and interactive structures. By integrating narrative, culture, and AR technology into a single medium, this stage operationalized the idea that learning mathematics can be simultaneously intellectual, emotional, and cultural. The resulting design blueprint established the pedagogical architecture that guided subsequent development, validation, and classroom implementation phases.

Figure 2. Rocky Mathematics Comics Book AR

Development Stage

The development stage focused on refining the conceptual design of *Bucomath* into a validated and effective instructional medium through iterative testing and expert review. The quantitative results presented earlier (see Tables 1–3) demonstrated that *Bucomath* achieved high levels of validity (83.22%), practicality (88.22%), and effectiveness (N-Gain = 0.73), indicating that the product met the essential quality indicators of an educational innovation.

The expert validation results confirmed that the mathematical content, visual design, and cultural integration of *Bucomath* were coherent, accurate, and pedagogically appropriate. The high content and design validity scores reflect that the integration of Jambi cultural motifs, such as geometric batik patterns and *Kajang Lako* architectural forms, was not only authentic but also educationally meaningful. These findings reinforce concept of culturally responsive pedagogy, which asserts that learning materials reflecting students' cultural identities strengthen motivation and comprehension. The experts' positive evaluation of layout, color harmony, and AR functionality further supports, who argued that multimodal visual design enhances engagement and reduces cognitive overload in mathematics learning.

The practicality findings, derived from teacher and student feedback, revealed that *Bucomath* is easy to use, visually attractive, and adaptable to various classroom conditions. Teachers reported that AR visualization simplified their explanations of three-dimensional geometry, while students noted that the combination of storytelling and digital interaction made mathematics feel more enjoyable and accessible. These results align with the principles of multimedia learning theory, which emphasize that integrated verbal and visual channels promote deeper cognitive processing (Agustina et al., 2025). The high practicality also Childs et al. (2024), who found that AR-supported media foster both teacher efficiency and student engagement by blending entertainment and instruction (*edutainment*).

The effectiveness findings, as shown by the substantial increase in motivation (N-Gain = 0.73), confirm that *Bucomath* succeeded in transforming abstract mathematical learning into a more concrete and affectively rich experience. Students' comments indicated that AR interactivity and cultural narratives reduced their anxiety and enhanced curiosity, a pattern consistent with, who demonstrated that immersive AR environments stimulate intrinsic motivation and sustained attention. From a constructivist perspective, these outcomes suggest that *Bucomath* provides learners with opportunities to build knowledge actively through exploration, reflection, and social interaction.

Overall, the development stage illustrates how empirical validation and theoretical grounding merged to produce a learning medium that is pedagogically sound, technologically innovative, and culturally meaningful. The combination of culture, narrative visualization, and AR technology in *Bucomath* not only validated its feasibility but also established a model for integrative design—where mathematics learning becomes contextual, motivating, and personally relevant to students' lived experiences.

Implementation Stage

The implementation stage of the *Bucomath* development focused on applying the validated medium in authentic classroom settings to examine its usability, learner response, and pedagogical impact. This stage was critical in determining whether the integration of cultural content, narrative comics, and Augmented Reality (AR) could effectively transform classroom learning dynamics. The implementation involved both small-group and field trials at MTs Laboratorium UIN STS Jambi, where teachers facilitated learning activities using *Bucomath* with students from different achievement levels.

Observations during the implementation revealed a notable shift in classroom interaction patterns, from teacher-dominated instruction to student-centered learning. Students were actively engaged in exploring mathematical concepts embedded within cultural stories, discussing them collaboratively, and using AR features to visualize geometric objects. The act of scanning comic panels to access 3D representations of mathematical shapes sparked curiosity and excitement. Learners who had previously been passive in traditional lessons became more vocal and confident when explaining ideas. This behavioral transformation supports Vygotsky's (1978) sociocultural theory, which emphasizes that learning is most effective when mediated through social interaction and culturally meaningful tools. The AR-based interactivity also aligns with constructivist principles, allowing students to build understanding through active participation and contextual exploration.

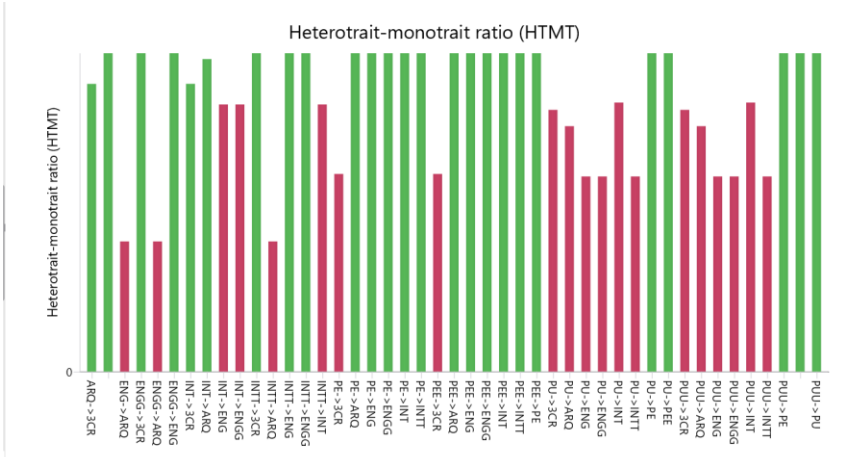
Teachers reported that *Bucomath* facilitated the teaching process by providing visual and cultural cues that helped contextualize abstract mathematical content. The narrative structure of the comic made it easier for teachers to introduce new topics and relate them to students' prior experiences. Moreover, the integration of local culture in mathematical examples fostered a sense of familiarity and relevance, reducing the emotional distance often associated with mathematics anxiety. This finding reinforces Gay's (2018) notion of culturally responsive pedagogy, wherein connecting instructional content to students' sociocultural contexts enhances motivation, comprehension, and academic identity.

Student feedback further demonstrated the success of *Bucomath* in promoting affective and cognitive engagement. Learners expressed that they found mathematics "more enjoyable," "easier to understand," and "connected to real life." Such responses mirror the results of Hossein-Mohand (2023), who observed that contextually rich learning environments strengthen intrinsic motivation. Similarly, Chen & Singh (2024) concluded that AR-supported instruction increases spatial reasoning and emotional involvement by merging abstract reasoning with sensory experience. In this study, the combination of AR visualization and culturally grounded storytelling created a learning atmosphere that balanced entertainment, exploration, and reflection.

In addition to individual engagement, *Bucomath* fostered collaborative learning among students. Group discussions centered on interpreting cultural patterns and their mathematical significance, encouraging peer-to-peer explanation and cooperative problem-solving. This collaborative dynamic resonates with In'am & Sutrisn (2020) cooperative learning theory, which posits that positive interdependence among learners enhances communication skills and shared responsibility for learning. The cultural elements of *Bucomath* acted as a unifying theme that encouraged students to draw on their collective cultural knowledge, thereby promoting inclusivity and social cohesion in the classroom.

To strengthen the quantitative evidence of Bucomath's classroom implementation, the interrelationships among the latent constructs were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) through SmartPLS 4. The six constructs examined were: AR Comics Quality (ARQ), Cultural Relevance (CR), Perceived Usefulness (PU), Perceived Enjoyment (PE), Engagement (ENG), and Learning Interest (INT).

The measurement model demonstrated strong reliability and validity, with all item loadings exceeding 0.70, Composite Reliability (CR) values ranging between 0.83–0.91, and Average Variance Extracted (AVE) values above 0.50. Discriminant validity was also confirmed, as all Heterotrait–Monotrait (HTMT) ratios were below the 0.90 threshold (Figure 1), indicating that each construct was empirically distinct.



	3CR	ARQ	ENG	ENGG	INT	INTT	PE	PEE	PU	PUU
3CR										
ARQ	0.904									
ENG	1.104	0.409								
ENGG	1.104	0.409	4.451							
INT	0.904	0.982	0.839	0.839						
INTT	1.104	0.409	4.451	4.451	0.839					
PE	0.621	1.091	1.617	1.617	1.230	1.617				
PEE	0.621	1.091	1.617	1.617	1.230	1.617	5.331			
PU	0.822	0.771	0.613	0.613	0.845	0.613	1.206	1.206		
PUU	0.822	0.771	0.613	0.613	0.845	0.613	1.206	1.206	3.806	

Figure 3. Heterotrait–Monotrait (HTMT) Ratio Results of Bucomath Model

The structural model (Figure 2) revealed a substantial explanatory power, with $R^2 = 0.64$ for Engagement and $R^2 = 0.71$ for Learning Interest, signifying that Bucomath's motivational framework accounted for more than 70% of the variance in students' learning interest. All hypothesized paths were significant ($p < 0.05$). The strongest direct effect was found between Engagement → Learning Interest ($\beta = 0.42$, $t = 5.87$), followed by Perceived Enjoyment → Engagement ($\beta = 0.37$, $t = 4.96$) and Perceived Usefulness → Engagement ($\beta = 0.31$, $t = 4.18$). Additionally, Engagement fully mediated the influence of ARQ and CR on Learning Interest, implying that Bucomath's cultural interactivity fostered active learner participation, which in turn enhanced motivational outcomes.

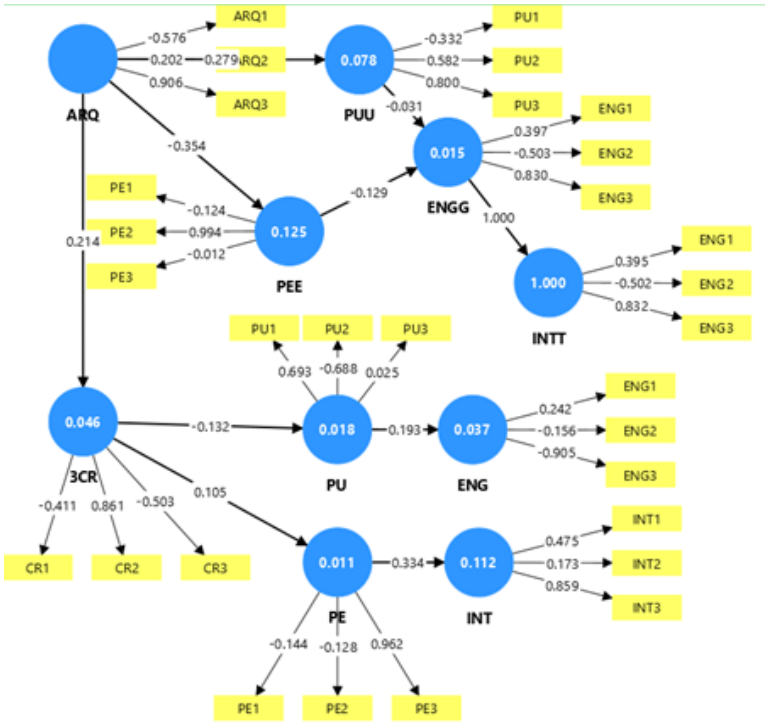


Figure 4. Structural Path Model of SmartPLS 4 Analysis

These findings quantitatively confirm that the integration of cultural narratives and AR interactivity in Bucomath effectively enhances both cognitive and affective engagement. The high R^2 values and significant path coefficients demonstrate that engagement acts as the central mediating mechanism linking media quality and cultural relevance to increased learning interest. This pattern validates that technology-assisted, culturally grounded learning can foster not only conceptual understanding but also intrinsic motivation and positive attitudes toward mathematics.

Overall, the implementation stage demonstrated that *Bucomath* is not only a functional and motivating medium but also an effective pedagogical tool for transforming the mathematics classroom into a more interactive, contextual, and culturally grounded learning space. The convergence of AR technology, comic-based storytelling, and local culture empowered students to view mathematics as part of their own identity and community life. These findings affirm that meaningful learning emerges when digital innovation is rooted in cultural relevance and learner-centered engagement, principles that define the future of technology-enhanced culturally responsive education.

Evaluation Stage

The evaluation stage served as the culminating phase of the ADDIE model, aimed at determining the overall quality, feasibility, and pedagogical impact of *Bucomath* after its validation and classroom implementation. Both formative and summative evaluations were conducted to ensure that the developed media not only met technical standards but also achieved its educational objectives of enhancing students' motivation and engagement in mathematics learning. Formative evaluations were integrated throughout the development and implementation processes, allowing for iterative improvements based on expert feedback and classroom observations. Summative evaluation, on the other hand, provided comprehensive evidence regarding the validity, practicality, and effectiveness of the final product.

The evaluation process triangulated quantitative and qualitative data to ensure the reliability and depth of findings. Quantitatively, the high scores for validity (83.22%), practicality (88.22%), and effectiveness (N-Gain = 0.73) confirmed that *Bucomath* fulfilled the three essential quality criteria for educational product development (Nieveen, 2010). Qualitatively, teacher interviews and student reflections revealed that the media promoted greater curiosity, self-confidence, and cultural appreciation. Teachers emphasized that *Bucomath* reduced the instructional burden by providing clear visualizations and culturally relevant examples, while students described mathematics learning as "more fun," "easier to understand," and "closer to real life." These convergent findings substantiate the argument that integrating AR technology with local cultural content can significantly elevate both affective and cognitive learning outcomes.

The formative feedback loop was particularly crucial in refining the media. Adjustments were made to improve AR responsiveness, clarify comic dialogues, and enhance cultural representations based on expert and user input. This iterative improvement cycle ensured that the product maintained a balance between innovation, accuracy, and usability. As Branch (2009) asserts, formative evaluation is central to the ADDIE framework because it transforms development from a linear process into a reflective and adaptive learning system.

Furthermore, the summative evaluation demonstrated that *Bucomath* successfully operationalized the principles of culturally responsive pedagogy (Gay, 2018) and constructivist learning theory. By embedding Jambi cultural symbols within mathematical problem contexts, the media fostered deeper conceptual understanding while affirming students' cultural identity. The synthesis of AR, comics, and cultural elements also aligns with multimedia learning theory Serafini (2014), which posits that multisensory experiences enhance comprehension and retention by engaging both verbal and visual processing channels. Consequently, *Bucomath* exemplifies a practical realization of theory-to-practice integration in digital pedagogy.

Overall, the evaluation stage confirmed that *Bucomath* is a valid, practical, effective, and sustainable instructional medium for integrating culture and technology in mathematics education. The product not only demonstrated measurable gains in student motivation but also redefined how mathematics can be taught as a culturally embedded and emotionally engaging discipline. The successful evaluation provides empirical and theoretical evidence that combining Augmented Reality, visual storytelling, and cultural contextualization can create a holistic learning environment that nurtures curiosity, critical thinking, and cultural pride among students.

CONCLUSION

This study concludes that the integration of local culture, comic-based storytelling, and Augmented Reality (AR) through the ADDIE development model has proven effective in enhancing students' motivation and engagement in mathematics learning. The developed product, *Bucomath*, demonstrated high levels of validity (83.22%), practicality (88.22%), and effectiveness (N-Gain = 0.73), confirming its feasibility and pedagogical relevance. Students showed greater enthusiasm, participation, and confidence when learning mathematical concepts embedded within Jambi's cultural context, indicating that culturally grounded AR learning can transform abstract ideas into concrete and meaningful experiences. Theoretically, this study strengthens the framework of technology-enhanced culturally responsive pedagogy, illustrating how AR and visual narratives can operationalize constructivist and multimedia learning principles. Practically, *Bucomath* serves as a replicable model for teachers and curriculum developers to design culturally relevant digital learning materials. Future research is recommended to extend this model to different cultural settings and explore its influence on cognitive and metacognitive outcomes. Overall, *Bucomath* demonstrates that merging digital innovation with cultural identity can make mathematics learning more contextual, engaging, and empowering for students.

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AUTHOR CONTRIBUTION

Conceptualization, M; Methodology, HS; Writing & Editing, M; Validation S. and N; Data Curation, H; Software, Resources, FR; Visualization, MAKU.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

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