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Jurnal Penelitian Ilmu Pendidikan

Volume 18, Nomor 2, 109 – 122, 2025

Development of Mathflip-Pad E-modules based on PBL and Muhammadiyah values to facilitate student engagement and mathematical communication

Tiara Friaesa Harsono[1*] and Unik Ambar Wati[2]

[1]Fakultas Ilmu Pendidikan, Universitas Negeri Yogyakarta, Sleman, D. I. Yogyakarta, Indonesia
Corresponding Author. e-mail: tiarafriaesa.2025@student.uny.ac.id

Abstract
Student engagement and mathematical communication are essential 21st-century competencies; however, many students still struggle to actively participate and express mathematical ideas in conventional classrooms. This study aimed to develop a MathFlip-Pad electronic module (e-module) based on Problem-Based Learning (PBL) and Muhammadiyah values and to examine its validity, practicality, and effectiveness in enhancing student engagement and mathematical communication skills. This study employed a Research and Development (R&D) method using the ADDIE model. The e-module was designed as a flipbook-style interactive learning media integrating PBL stages and Islamic values. Validation involved subject matter, media, and pedagogy experts, followed by a limited trial with eighth-grade students at a Muhammadiyah junior high school. Data was collected through expert validation, response questionnaires, and classroom observation. Expert validation scores for the material and media were 90.63% and 92.2% (highly valid), while student and teacher responses were 89.5% and 90.6% (very good). Observations showed that 92% of students actively participated in discussions, 95% engaged in Polypad exploration, and 87% used appropriate mathematical language. The study concludes that the *MathFlip* Pad e-module is feasible and effective in enhancing engagement and mathematical communication.
Keywords: E-module; problem-based learning; mathematical communication; student engagement; Muhammadiyah values

How to Cite (APA): Harsono, T. F., & Wati, U. A. (2025). Development of Mathflip-Pad E-modules based on PBL and Muhammadiyah values to facilitate student engagement and mathematical communication. *Jurnal Penelitian Ilmu Pendidikan, 18*(2), 109-122. doi: https://doi.org/10.21831/jpip.v18i2.91610

Received 14-10-2025; Received in revised from 26-10-2025; Accepted 2-11-2025

INTRODUCTION

In recent years, mathematical communication has been increasingly recognized as a core competency that determines the quality of mathematics learning. The process standards formulated by the NCTM (2000) emphasize that communication is not merely the ability to state answers but rather the process of constructing, mathematizing, and conveying ideas in a coherent and reasoned manner (Pratiwi et al., 2025). This competency is a prerequisite for numeracy literacy as emphasized in the Merdeka Curriculum, which requires students to understand concepts, explain their thoughts, and use mathematical representations appropriately in the context of life (Kemdikbudristek, 2022). At the elementary school level,

mathematical communication skills serve as a bridge to conceptual understanding, especially when students are faced with abstract concepts such as fractions (Khadka, 2024).

Studies in mathematics education show that students' ability to communicate ideas is an important foundation for the formation of sustainable conceptual understanding. Boaler (2016) emphasizes the link between mathematical communication and the formation of positive dispositions toward mathematics, including confidence and courage to express strategies. National Research Council (2012) adds that this ability develops when students are given the opportunity to explore the relationships between visual, symbolic, and contextual representations in an integrated manner. In fraction material, coordination between these representations is very important because misconceptions often arise due to fragmented understanding (Farokhah et al., 2025). Without the support of media and learning scenarios that allow for gradual exploration of meaning, the process of mathematical communication is easily hampered, making it difficult for students to explain the conceptual reasons behind the strategies they use (Siegler et al., 2011).

However, learning practices in the field show that this ability has not been optimally developed. A study by Rodríguez-Martínez et al. (2023) shows that many elementary school students still understand fractions procedurally without establishing meaningful relationships between visual representations, symbols, and context. The findings of Manjani et al. (2024) also show the dominance of mechanistic exercises in the classroom, which limit the space for mathematical dialogue and meaning construction. Although some studies report an increase in procedural outcomes through digital media Sari et al. (2024), this improvement is often not accompanied by growth in conceptual understanding and communication skills. This discrepancy highlights the limitations of previous approaches. This condition is closely related to low student engagement, particularly cognitive and behavioral engagement, which, according to Fredricks et al. (2004), is a prerequisite for participation in quality mathematical discussions. Research by Green (2024) and Lestari (2020) even shows that weak engagement is one of the causes of the decline in students' ability to explain conceptual reasons.

Empirical findings from class IV C of Muhammadiyah Condongcatur Elementary School reinforce this pattern: students can solve fraction problems procedurally but are not yet able to explain the mathematical reasoning behind the strategies they choose. A few high-ability students frequently dominate group discussions, while other students typically passively follow the group's decisions without making any significant contributions. Teachers identify the need for learning media that not only displays visual representations but also triggers mathematical conversations, increases engagement, and designs investigative processes so that all students have space to participate. In this context, student engagement and mathematical communication emerge as two interrelated aspects that must be deliberately facilitated through the design of learning media and scenarios (Nashihah, 2020).

Problem-Based Learning (PBL) has emerged as a promising approach because it uses contextual problems as triggers for inquiry that requires collaboration, negotiation of meaning, and the articulation of ideas (Savery, 2006). Drageset (2010), through a meta-analysis, shows a consistent positive correlation between the use of PBL and improved critical thinking and communication skills, which can be further strengthened through the integration of digital technology. Virtual manipulatives such as Polypad provide opportunities for students to experiment with dynamic mathematical representations, receive immediate visual feedback, and create shared objects that mediate discussion. These features have the potential to increase student engagement and improve the quality of mathematical communication in fraction learning (Wahyuni & Rejeki, 2022).

Another relevant pedagogical dimension is the Muhammadiyah school context. Muhammadiyah values such as justice, mutual assistance, and simplicity are expected to be reflected in the learning process. The integration of Islamic values into mathematics learning becomes meaningful when placed in authentic situations that encourage moral reflection. Aliyah et al. (2025) and Rizal et al. (2023) emphasize that the integration of Islamic dialogical values can

enrich the learning process without reducing academic depth. In fraction material, the context of sharing cake and discussing justice provides a natural opportunity to link mathematical representations with an understanding of values.

In summary, previous research shows both great opportunities and shortcomings: many media developments focus on improving procedural skills and rarely test the simultaneous integration of mathematical communication, learning engagement, and religious values. Also, there aren't any studies that clearly combine the PBL framework, Polypad digital manipulatives, and Muhammadiyah values in a single learning media framework that has been tested by experts, users, and people watching the learning process. This gap underscores the need for research that designs and tests media that integrates these three aspects in a comprehensive manner.

Based on this gap, this study developed MathFlip-Pad, a prototype e-module that integrates PBL, Polypad digital manipulatives, and Muhammadiyah values in the context of the "Sharing Birthday Cake" problem for fourth-grade fraction learning. The objectives of this study are (1) to develop a MathFlip-Pad e-module that meets the criteria of feasibility and practicality based on expert assessment and user response and (2) to analyze how the e-module facilitates student engagement and mathematical communication during fraction learning at SD Muhammadiyah Condongcatur.

Conceptually, this study offers a model of integrating PBL, digital manipulatives, and Islamic values into a single learning media platform, a combination that has not been widely explored in the literature on elementary school mathematics media development. Practically, MathFlip-Pad media provides a concrete example of how mathematics learning can be designed to be more interactive, meaningful, and nuanced with Islamic values without sacrificing conceptual clarity. This approach is expected to broaden the discourse on learning media development and inspire teachers in designing interactive mathematics learning based on Islamic values.

METHODS

This study used a research and development approach with the ADDIE (Analyze, Design, Develop, Implement, Evaluate) model developed by Branch (2010) as a systematic framework for designing, developing, and refining the MathFlip-Pad learning media. In the Analysis stage, an analysis of the curriculum, student needs, and class characteristics was conducted. The design stage included the design of PBL scenarios and teaching modules. The Develop stage included the production of e-modules, expert validation, and revision. The Implement stage included teacher training and classroom learning. The Evaluate stage involved the collection of observation data, questionnaires, and descriptive analysis. The media development procedure is visualized in Figure 1.

The research was conducted at SD Muhammadiyah Condongcatur, Sleman, Yogyakarta, in the odd semester of the 2024/2025 academic year. The research subjects consisted of 37 fourth-grade students and one mathematics teacher. The class was selected purposively based on initial observations that indicated a need for more interactive media to improve mathematical engagement and communication. The teacher acted as the main facilitator, while the researcher assisted and conducted systematic observations during product testing.

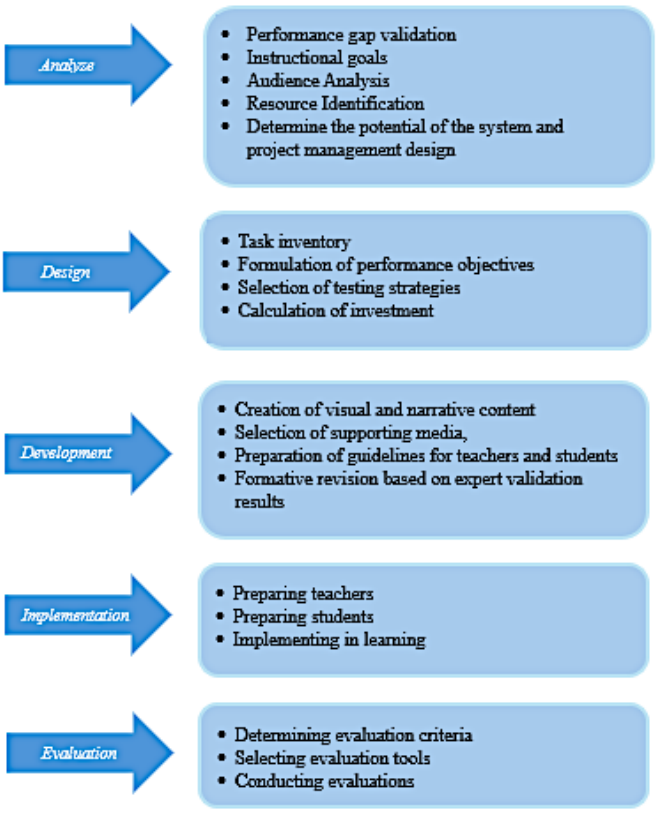

Figure 1. ADDIE stages in the research

The feasibility validation technique for the digital flipbook media in this study was obtained from a questionnaire using a research instrument scoring method, which was then filled out by experts, namely media experts and subject matter experts. Table 1 is an assessment table.

Table 1. Validation scoring scale

Score	Category
4	Strongly Agree
3	Agree
2	Somewhat Disagree
1	Disagree

The subject matter expert validation instrument includes six assessment criteria, namely competency alignment, material accuracy, technical quality, value integration, learning approach, and language, with a total of 16 indicators. Media expert validation includes three major criteria, namely program appearance, efficiency aspects, and technical quality, with a total of 16 indicators. Each validator fills in the scores in columns 4–3–2–1 according to their perception of media quality. Validity is calculated using the following formula:

$$P = \frac{Total\ Score}{Maximum\ Score}\ x\ 100\%$$

The eligibility criteria for the developed learning media are determined by referring to the interpretation guidelines presented in the instrument shown in Table 2. These criteria are used as a benchmark to classify the level of media validity based on the percentage score obtained from the expert validation results. The percentage ranges indicate the quality category of the media, ranging from very low to very good.

Table 2. Media validity interpretation criteria

Percentage	Category
81–100%	Very Good
61–80%	Good
41–60%	Fair
21–40%	Poor
0–20%	Very low

Source: (Riduwan & Sunarto, 2012)

In addition to expert validation, this study also involved student and teacher response questionnaires to assess the practicality and acceptance of MathFlip-Pad during learning. The student questionnaire consists of 10 statements that measure the benefits of the media, ease of use, and support for understanding fractions. The teacher questionnaire consists of 15 statements covering aspects of student engagement, mathematical communication, integration of PBL and Muhammadiyah principles, and overall media quality. Both questionnaires use a four-point Likert scale, namely:

Table 3. Validation scoring scale

Score	Category
4	Strongly Agree
3	Agree
2	Somewhat Disagree
1	Disagree

The scores obtained from the student and teacher response questionnaires are analyzed using the following formula to determine the percentage of responses:

$$P = \frac{Total\ Score}{Maximum\ Score}\ x\ 100\%$$

The resulting percentage is then interpreted based on the criteria presented in Table 4. These interpretation criteria serve as a reference for categorizing the level of students' and teachers' responses toward the practicality, effectiveness, and overall acceptance of the MathFlip-Pad learning media.

Table 4. Interpretation of Student and Teacher Response Questionnaires

Percentage	Category
81–100%	Very Good
61–80%	Good
41–60%	Fair
≤ 40%	Poor

Source: (Widyoko, 2016)

RESULTS AND DISCUSSION

Results

Learning was developed in line with the learning outcomes (CP) of phase B of the independent curriculum and integrated the Problem Based Learning (PBL) approach and the values of Kemuhammadiyahan, which are characteristic of Muhammadiyah schools. The development of MathFlip-Pad was carried out systematically using the ADDIE model, starting from the needs analysis stage, product design, development, and implementation in real classrooms to evaluate the effectiveness of the media.

Table 5. Learning Outcomes and Objectives

Learning Outcomes	Learning Objectives
Element: Numbers	
Students can compare and order fractions with a numerator of one (e.g., 1/2, 1/3, 1/4) and fractions with the same denominator (e.g., 2/8, 4/8, 7/8). They can recognize equivalent fractions using images and mathematical symbols.	a. Students can compare, add, and subtract fractions accurately through exploration in Polypad. (C4) b. Students can explain the concept of fractions in their own words in the context of fair sharing. (C2) c. Students can collaborate effectively in groups with clear role division. (P3)

The analysis stage began with classroom observations and interviews with the fourth-grade mathematics teacher. The observations showed a predominance of teacher-centered activities and good procedural mastery by students, but a weakness in their ability to explain mathematical reasoning and low involvement in discussions. The teacher confirmed this by stating:

> *"The children are actually quick at calculating, but when asked to explain their reasoning, they often have difficulty answering conceptually. They know how to calculate, but do not yet fully understand why that method is used."*

This condition is consistent with previous research findings, which show that elementary school students often master procedures without a deep understanding of concepts (Lestari, 2020). This situation reinforces the need for more interactive, contextual, and visualization-based learning media to stimulate active engagement and strengthen mathematical understanding and communication. The results of the needs analysis and development objectives are summarized in Table 6.

Table 6. Mapping of Needs Analysis and Formulation of Media Objectives

Initial Condition Indicators	Key Findings	Media Implications
Learning patterns	Lecture-dominated, mechanistic practice, minimal discussion	Media should trigger PBL and group collaboration
Mastery of material	Students are proficient in calculations but weak in explaining concepts/steps	Media should combine digital concrete exploration, narration, and explanation excercises
Engagement	Class participation is passive; students rarely ask questions	Media based on problem-solving activities and exploratory/visual tasks
Values	Teachers want to instill justice and cooperation	Modul must frame the socio-religious context (Islamic/Muhammadiyah values)
Resources	The school has limited digital devices, but teachers and students are familiar with ICT	Media is easy to operate (flipbook, Polypad templates), with minimal infrastucture requirements

Based on this table, the goal of developing MathFlip-Pad is to provide media that combines contextual narratives, Polypad visual exploration, group collaboration, and the integration of Islamic values with a practical and efficient design for the real setting of Muhammadiyah elementary schools. The design stage guides the creation of MathFlip-Pad content through three main activities: "sharing birthday cake" introduces fractions through a story; "Polypad" activities help with comparing and ordering fractions; and "reflecting on the values of justice and mutual assistance" does just that. Each episode is illustrated in a structured storyboard, in accordance with PBL syntax. The application of the enactive-iconic-symbolic principle (Bruner) is emphasized.

The media was created using Canva, converted into an interactive Heyzine flipbook, and integrated with a QR code leading to Polypad. Instructional support is reinforced through Teacher and Student Guides that follow the MathFlip-Pad lesson flow. The entire structure is narrative and is based on the Problem-Based Learning (PBL) syntax with five main stages: contextual problem orientation ("sharing birthday cake"), organizing students into groups to define and analyze problems, independent investigation using Polypad to compare, add, and subtract fractions visually and explore strategies, developing and presenting group solutions mathematically and narratively, and analyzing solutions and reflecting on values both in class forums and individually. Each stage is accompanied by sparking questions and reflections, with the values of justice, ta'awun (mutual cooperation), and qana'ah (contentment) explicitly structured in each activity.

Figure 2. Overview of the mathflip-pad media

During the implementation stage, teachers were involved in pre-implementation activities to ensure a shared understanding of the learning flow, the use of MathFlip-Pad, and the integration of the Problem-Based Learning approach and Muhammadiyah values in the teaching tools used. This involvement was carried out through reviewing the teacher's guide, discussing activity scenarios, and aligning perceptions regarding the role of facilitators during the intervention.

During the learning process, the researcher acted as the main facilitator to ensure that the MathFlip-Pad implementation scenario ran according to plan, while the teacher acted as a classroom assistant who helped manage the learning situation and observed student activities.

This arrangement of roles allowed teachers to understand the media implementation process while maintaining a conducive classroom atmosphere. The entire implementation process was designed so that teachers would have a comprehensive understanding of the use of the media so that the results of the intervention would remain relevant to learning practices in schools.

The evaluation stage is implemented comprehensively to review the quality of MathFlip-Pad in terms of substance, design, and implementation in the classroom. The evaluation is based on criteria set out in expert validation instruments, student and teacher response questionnaires, and observation sheets on mathematical engagement and communication during learning. Data collection and analysis were carried out systematically to obtain an objective picture of the media's feasibility, user acceptance, and the success of MathFlip-Pad in encouraging active participation and strengthening students' mathematical communication. The results of each evaluation instrument are then described in a structured manner in Table 7.

Table 7. Expert validation results

Validator Name	Score Obtained	Maximum Score	Percentage
Siti Maryatul Kiptiyah, S.Si., S.Pd., M.Pd.	58	64	90.625%

The results in Table 7 show that the subject matter experts' assessment of MathFlip-Pad obtained a feasibility percentage of 90.625%. This percentage is in the Very Valid category, meaning that the content, conceptual accuracy, value integration, and application of PBL syntax are considered adequate for use in learning. An in-depth review by subject matter experts also highlighted the need to refine the story context, use a more consistent enactive-iconic-symbolic flow, and emphasize the PBL stages to make the module structure more systematic. This input was incorporated during the formative revision stage to produce a more focused and user-friendly version of the module.

Table 8. Results of media expert validation

Validator Name	Score Obtained	Maximum Score	Percentage
Dr. Yosua Damas Sadewo, S.Pd., M.Pd.	59	64	92.2%

Table 8 shows that the media obtained a score of 59 out of 64, with a percentage of 92.2%, and is included in the Very Valid category. This indicates that MathFlip-Pad has met the standards of visual display, design consistency, navigation, readability, and integration of interactive elements. The improvement suggestions provided by media experts include optimizing text size, providing interactive quiz features, and improving the user guide. All these inputs were accommodated in the revision to make the product more compatible with classroom needs and student devices.

Table 9. Student response survey results

Aspect	Average Score	Category
Appearance Appeal	4.2	Very Good
Conceptual Understanding	4.1	Very Good
Engagement & Collaboration	4.3	Very Good
Value Integration	4.4	Very Good
Learning Motivation	4.5	Very Good
Average Percentage	**89.5%**	**Very Good**

The results in Table 9 show students' high enthusiasm for MathFlip-Pad, with an overall percentage of 89.5%. The highest scores were in the areas of motivation and value integration. Students felt that the contextual stories, Polypad exploration activities, and discussion activities made learning more meaningful. These responses indicate that the visual-interactive approach and problem flow successfully stimulated student participation in the learning process.

Table 10. Teacher response questionnaire results

Assessment Aspect	Score	Category
Student Engagement	4.2	Very Good
Mathematical Communication	4.1	Very Good
Integration of PBL & Values	4.4	Very Good
Media Suitability	4.3	Very Good
Percentage	**90.6%**	**Very Good**

Teachers assessed that MathFlip-Pad was very helpful in facilitating discussion, concept exploration, and understanding of values. The media was considered to enrich learning variety and increase student engagement compared to the lecture method that previously dominated. To validate the qualitative perceptions from the student and teacher response questionnaires, systematic observation of the learning process was conducted using structured observation sheets. The results of the observation of student engagement and mathematical communication during learning are presented in Table 11 and Table 12.

Table 11. Results of student engagement observations during learning with mathflip-pad

Engagement Indicators	Number of Students	Percentage	Category
Behavioral Engagement			
Students actively ask questions or respond to teachers' questions	33	89%	Very High
Students actively participate in Polypad exploration activities according to instructions.	35	95%	Very High
Students contribute to group discussions with ideas or responses.	32	86%	Very High
Cognitive Engagement			Very High
Students try different strategies in solving fraction problems	31	84%	Very High
Students connect Polypad representations with previously learned fraction concepts.	33	89%	Very High
Emotional Engagement			Very High
Students show enthusiasm and positive expressions during learning	34	92%	Very High
Average Engagement		**89.3%**	**Very High**

Observational data shows a high level of student engagement during the implementation of MathFlip-Pad. In terms of behavioral engagement, 89-95% of students actively asked questions, explored Polypad, and contributed to group discussions. Exploration of Polypad reached the highest percentage (95%), indicating that digital manipulatives are effective in attracting active student participation. In terms of cognitive engagement, 84-89% of students tried different strategies and connected representations with fraction concepts. Emotional engagement was also high, with 92% of students displaying enthusiasm and positive expressions during learning, in line with student questionnaire scores on learning motivation (M=4.5). The average engagement reached 89.3%, indicating that MathFlip-Pad successfully facilitated all three dimensions of engagement (behavioral, cognitive, and emotional) simultaneously.

Table 12. Results of student communication observations during learning with mathflip-pad

Mathematical Communication Indicators	Number of Students	Percentage	Category
Representation			
Students use visual representations (pictures, Polypad models) to explain fraction concepts	34	92%	Very High
Students consistently connect visual representations with mathematical symbols (fraction notation a/b)	31	84%	High
Verbal Explanation			
Students can explain the mathematical reasoning behind the chosen strategy or procedure.	33	89%	Very High
Students use appropriate mathematical terms when explaining fraction concepts.	31	84%	High
Justification			
Students provide logical reasons or evidence for their fraction answers when asked.	30	81%	High
Average Mathematical Communication		**86.0%**	**High**

The observation data shows a high level of mathematical communication among students. In terms of representation, 92% of students used visual representations accurately, and 84% consistently linked visual representations to mathematical symbols, demonstrating the ability to switch between representations as described by Bruner. In terms of verbal explanation, 89% of students were able to explain mathematical reasoning coherently using appropriate terminology (84%). In terms of justification, 81% of students were able to provide logical reasons for their answers. Although the percentage of justification was lower than in other aspects, this still shows that most students have developed the ability to articulate conceptual reasoning. The average mathematical communication score was 86.0%, indicating that the Math Flip-Pad successfully facilitated the three aspects of mathematical communication (representation, verbal explanation, and justification) in accordance with NCTM standards.

Findings from expert validation, user responses, and learning process observations show positive consistency. These results will be analyzed in more depth in the context of learning theory and literature related to the development of mathematics learning media.

Discussion

It has been confirmed by experts that using Problem-Based Learning (PBL), Polypad digital manipulatives, and Muhammadiyah values together in flipbook-based media creates a meaningful and integrated learning structure. These results are in line with the findings of Funke (2022) and Savery (2006), who stated that PBL encourages higher-order thinking, discussion, and the construction of more coherent mathematical explanations. However, the unique contribution of MathFlip-Pad lies in the deliberate synergy between these three elements, which in previous literature were generally studied separately. Funke (2022) found that PBL influences critical thinking but does not always improve the quality of mathematical communication, while Moyer-Packenham and Westenskow (2013) showed that digital manipulatives improve visual representation but do not necessarily increase emotional engagement and intrinsic motivation. The integration of religious values is reported to enrich the meaning of learning, but it has not been widely tested in conjunction with interactive technology in a unified ecosystem. Within the MathFlip-Pad framework, PBL functions as a cognitive framework that encourages in-depth investigation, Polypad acts as a visual mediator that facilitates gradual representation transitions, and Islamic values provide an emotional and moral dimension so that learning feels relevant and personal.

Data from observations of the learning process (Table 11) support empirical validation of student engagement. Observations show that 95% of students actively explored Polypad, 89% asked or responded to teachers' questions, and 92% showed enthusiasm during learning. This pattern is consistent with Fredricks et al. (2004) multidimensional engagement framework, which separates engagement into behavioral, cognitive, and emotional dimensions. The average engagement level of 89.3% indicates that the PBL design using the authentic context of “Sharing Birthday Cake” effectively activated engagement in all three dimensions. These findings are also in line with the idea that relevant activities that provide room for exploration will increase student engagement Fredricks et al. (2004).

According to Moyer-Packenham and Westenskow (2013), the mechanism of instant visual feedback that stimulates curiosity and independent experimentation can explain Polypad's role in boosting engagement. In practice, Polypad functions as a shared object that mediates interactions between students during discussions, thereby strengthening opportunities for independent negotiation of meaning and re-representation of concepts. Thus, the use of digital manipulatives not only enriches visual representation but also supports the social-cognitive dynamics that are essential for collaborative learning.

The integration of Muhammadiyah values was well received by students and teachers, and this supported the idea of meaningful learning. Aliyah et al. (2025) and Rizal et al. (2023) argued that when values are incorporated through relevant contexts and reflective dialogue, students are better able to relate academic concepts to their life experiences. In MathFlip-Pad,

the values of fairness and mutual assistance are embodied through situations involving sharing cake and group work so that these values are not presented as abstract moral additions but as aspects directly connected to the concept of fractions. The positive impact on motivation and learning comfort can be seen from the percentage of student responses of 89.5% and excellent teacher responses of 90.6%. These results are in line with the findings of Putri et al. (2020), which show that interactive digital media can increase interest through attractive visual design and easy navigation. In the context of this study, these factors are reinforced by the PBL structure and value relevance, creating an engaging and meaningful learning experience.

The success of the media in facilitating mathematical communication is validated by observation data (Table 12). In detail, it was found that: (1) in terms of representation, 92% of students used visual representations accurately, and 84% were able to relate visual representations to mathematical symbols, reflecting the ability to switch between representations in accordance with the dual representation theory; (2) in terms of verbal explanation, 89% of students were able to explain mathematical reasons, and 84% used appropriate mathematical terms; (3) in terms of justification, 81% of students provided logical reasons for their answers. The average mathematical communication score of 86.0% indicates that MathFlip-Pad effectively facilitates the three aspects of mathematical communication outlined by NCTM (2000), namely representation, verbal explanation, and justification.

This study adds to the body of research by showing that using PBL, digital manipulatives, and religious values all at the same time in a single learning environment can have a positive feedback loop that improves both mathematical engagement and communication. This enriches the literature on mathematics media development at the elementary school level, especially in the Indonesian context, which has not yet explored this kind of integrative model. Practically, MathFlip-Pad provides a concrete prototype that can be used as a reference for media developers and teachers to design interactive, authentic, and value-based mathematics learning.

However, this study has limitations that must be acknowledged honestly. First, the implementation was only carried out in one short learning session, so it cannot describe the long-term impact or sustainability of students' mathematical communication development. After a few weeks, the magnitude of the effects may decrease because the novelty effect may have had an impact on the observed effects. To assess sustainability, further research with continuous implementation for at least one semester is needed. Second, the research subjects were limited to one class in one school with specific sociodemographic characteristics, so generalization to other school contexts must be done with caution. Third, since the researchers themselves conducted observations of engagement and communication, it is impossible to rule out the possibility of observer bias and changes in the class's natural dynamics because of their presence. To overcome these limitations, future studies are recommended to use a longitudinal design, cross-context samples, and independent observers or data triangulation to increase objectivity.

Based on these limitations, several priority areas for further research include (1) testing long-term effectiveness through continuous implementation for at least one semester and measuring retention and transfer of fractions to other mathematical topics; (2) multi-context testing in various types of schools to test the generalization and adaptability of the model; (3) comparative studies between MathFlip-Pad and alternative media that only contain one component (e.g., PBL alone, Polypad without value integration, or traditional learning) to identify the relative contribution of each component; (4) integration of learning analytics features in Polypad for real-time tracking of engagement and communication, which can support adaptive learning; (5) exploration of the model's application to other mathematical topics such as decimals, ratios, and integer operations; (6) in-depth qualitative investigation of the process of internalizing religious values through phenomenological interviews or narrative analysis; and (7) development of professional development modules for teachers so that media implementation can achieve high fidelity and be adapted to the context of each school.

The practical implications of this study are important for education practitioners. The results show that using digital manipulatives and value contexts in real-life PBL tasks can make students more interested and improve their communication skills. This means that these tasks should be changed to fit fraction learning units. For school managers and policymakers, these findings indicate that investing in simple digital infrastructure, providing time for PBL implementation, and teacher training programs for the use of digital manipulatives and value integration can be effective strategies for improving the quality of mathematics learning. In addition, curriculum developers can consider modules that include contextual value components so that they add not only cognitive aspects but also value and affective aspects.

In conclusion, this study shows that MathFlip-Pad offers an integrated approach that can improve students' multidimensional engagement and mathematical communication in fourth-grade fraction learning. Although the results are promising, claims regarding long-term effectiveness and generalization should be interpreted with caution given the limitations of this study's design. Therefore, these findings should be viewed as preliminary evidence that motivates further, broader, and more in-depth studies, as well as a practical impetus to test the adaptation of this media in diverse school contexts.

CONCLUSION

The Math Flip-Pad e-module is an interactive flipbook-style mathematics learning tool based on problem-based learning and enriched with Muhammadiyah values. It was successfully developed and rigorously validated by subject-matter, media, and pedagogy experts, and was rated as very valid. Practicality tests and classroom trials with grade VIII students showed that the module is highly usable for teachers and engaging for learners. Students became more active, collaborative, and enthusiastic during learning, and they demonstrated significant improvement in mathematical communication skills, including clearer explanations, more accurate use of mathematical language, and stronger discussion of problem solutions. The integration of values provided meaningful contextualization that supported character education and increased student interest and the relevance of learning tasks.

These findings indicate that the combination of problem-based learning, digital media, and contextually relevant values can effectively promote student engagement and higher-order skills. Therefore, educators and curriculum developers are encouraged to adopt similar instructional models. Considering the limited scale of this study, further research and development with larger and controlled samples are recommended to examine long-term retention, adaptability to different grade levels or subjects, and the interaction between e-module design and teacher facilitation strategies. Overall, the Math Flip-Pad e-module represents a promising and scalable approach that aligns pedagogy with cultural and ethical relevance to foster both academic competence and character development.

ACKNOWLEDGEMENT

The researchers express their appreciation to SD Muhammadiyah Condongcatur for granting permission and providing support during the learning media trial process. Thanks, are also extended to Mrs. Siti Maryatul Kiptiyah, S.Si., S.Pd., M.Pd. as the subject matter expert and Mr. Dr. Yosua Damas Sadewo, S.Pd., M.Pd. as the media expert for their time, input, and assessment of the product's quality. The same recognition is given to Mr. Fauzi Nur Hadi, S.Si., and all the students of class IV C who actively participated in the implementation of Math Flip-Pad. The contributions of all parties were instrumental in refining the media and completing this research.

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