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The impact of Ethno-Realistic Mathematics Education-based e-module in strengthening students' problem-solving abilities

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Abstract

Mathematics education in Indonesia faces challenges primarily due to the limited problem-solving skills of students, prompting a need for effective teaching materials to enhance classroom learning. Despite this, many educators still rely on conventional methods that are less effective in fostering mathematical understanding. Consequently, there is a demand for alternative resources that can better support mathematics education. This study aims to develop a valid and practical e-module based on Ethno-Realistic Mathematics Education (Ethno-RME) to improve problem-solving abilities among eighth-grade students. Employing a design research approach within the development studies framework, the study includes preliminary and formative evaluation stages. Evaluation tools encompass expert assessments of content and media quality, walkthroughs, documentation, and problem-solving assessments. The outcome is an Ethno-RME-based e-module focused on number patterns, validated through expert reviews and positively evaluated for practicality by students. This research highlights the e-module's potential to significantly enhance students' mathematical problem-solving skills, offering educators an innovative tool to support effective mathematics teaching.

Keywords: Design Research; Ethno-RME; Impactful e-Module; Problem-Solving Abilities

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Introduction

The National Council of Teachers of Mathematics (NCTM) emphasizes that problem-solving constitutes the primary objective of mathematics education within school settings (Mundy, 2000; Haji, 2019). This emphasis underscores its pivotal role not only as an educational goal but also as a fundamental method for teaching and learning mathematics (Posamentier & Krulik, 2008; Posamentier et al., 2006; Schoenfeld, 1985). This educational focus aligns with the contemporary educational priorities encapsulated by the 4Cs framework—Critical Thinking and Problem Solving, Communication, Collaboration, Creativity, and Innovation—designed to equip students for the challenges of the 21st century (Thornhill-Miller et al., 2023). Furthermore, proficiency in problem-solving is indispensable beyond academic realms, proving essential in navigating everyday challenges and professional domains (Elaby et al., 2022; Sridana & Sarjana, 2020; Yasin et al., 2020). Thus, it stands as a crucial skill requisite for students in the current educational landscape.

Conversely, mathematics education in Indonesia confronts a persistent issue with students limited problem-solving abilities, as evidenced by findings from assessments such as the Program for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS) (Ismawati et al., 2023; Wijaya et al., 2024). Indonesian students demonstrate proficiency primarily in routine problems while grappling with mathematical challenges linked to everyday scenarios (Fadillah & Wahyudin, 2022; Meutia & Ikhsan, 2020). This trend reflects a curriculum that emphasizes abstract mathematical concepts over practical applications, thereby hindering students' comprehension of mathematics' relevance to their daily lives (Yuristia & Musdi, 2020) and failing to foster an engaging learning environment that motivates students. Consequently, the current landscape of mathematics education in Indonesia faces the critical imperative of enhancing students' problem-solving skills, attributed to an emphasis on routine problem-solving and a lack of integration of real-life contexts in teaching methodologies.

During preliminary research at SMP Muhammadiyah 6 Yogyakarta, similarly low problem-solving abilities among students were observed. Figure 1 illustrates the results of the pre-test conducted to assess students' proficiency in problem-solving. It illustrates that the indicator for identifying data sufficiency in problem-solving achieved a score of 87, representing 49.43% of the maximum score.

Additionally, the indicator for creating mathematical models from everyday problems and solving them attained a score of 71, equivalent to 53.78% of the maximum score. The indicator focusing on selecting and applying strategies to solve mathematical problems scored 67, accounting for 38.06% of the maximum score. Moreover, the indicator for explaining results based on the initial problem and verifying their correctness scored 84, which is 47.73% of the maximum score. Finally, the indicator for applying mathematics in meaningful contexts scored 68, representing 51.52% of the maximum score. In summary, the average problem-solving ability of students is 47.6%.

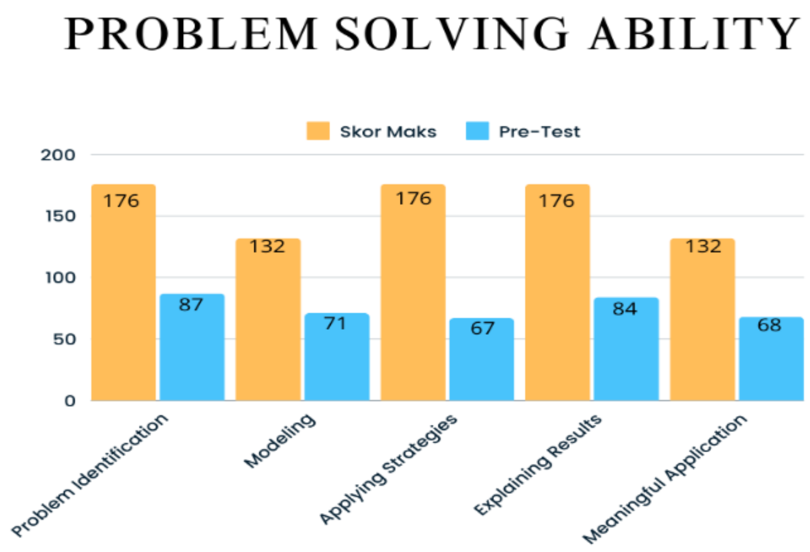

Figure 1. Pre-test of problem-solving ability

The ineffective problem-solving abilities of students can be attributed to traditional teaching methods, which often fail to engage students deeply in understanding mathematical concepts (Alam & Mohanty, 2023; Septriyana et al., 2019). Interviews with teachers reveal a common instructional approach where material is delivered, followed by textbook examples and exercises, which may not sufficiently stimulate student interest. Utilizing mathematics learning media that incorporate audio-visual elements is advocated as essential for enhancing student engagement (Widodo, 2018). Research by Aulia and Prahmana (2022) underscores the necessity for innovative approaches in mathematics education, highlighting electronic modules as a viable solution. These modules enable independent learning among students while offering teachers opportunities to present material in more dynamic and interactive ways (Rawashdeh et al., 2021). Therefore, updating teaching resources emerges as crucial in revitalizing mathematics learning activities.

Previous research has demonstrated that e-modules can enhance students' learning motivation tailored to their individual capacities (Ismaniati & Iskhamdhanah, 2023) and bolster their proficiency in mathematical problem-solving (Rakhmawati et al., 2023; Putri & Junaedi, 2022). However, interview findings with teachers indicate a current lack of electronic modules specifically designed to enhance mathematical problem-solving skills. This gap is underscored by responses detailing the prevalent use of traditional teaching materials, as depicted in Figure 2, highlighting the limited adoption of e-modules in educational practice.

In this study, alongside the utilization of instructional media, an innovative learning approach integrates mathematics with art and culture (Prahmana, 2022). This approach opens avenues for more engaging and relevant teaching and learning experiences, particularly through the exploration of Gringsing batik motifs (Permita et al., 2022). The incorporation of cultural contexts is widely recognized for its efficacy in comprehending and applying mathematical concepts, particularly in geometry, within the rich cultural heritage of batik, Indonesia's traditional fabric (Muhammad et al., 2023; Prahmana & D'Ambrosio, 2020). Moreover, an analysis of 50 articles published in scientific journals, as depicted in Figure 3, reveals a minimal exploration of the batik context in ethnomathematics studies concerning number pattern materials. Therefore, this research introduces a pioneering approach by investigating and analyzing the potential relationship between Yogyakarta batik contexts and number pattern materials.

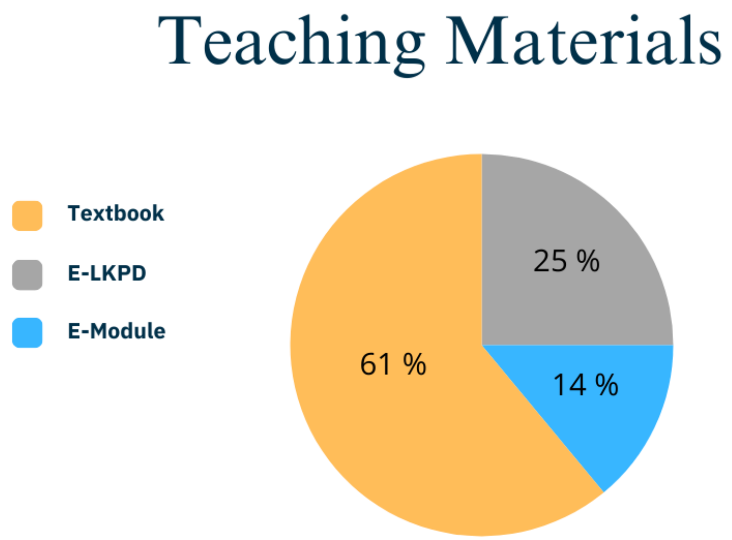

Figure 1. Teaching materials needs

The integration of cultural contexts to aid students in understanding and contextualizing mathematics learning is known as Ethnomathematics (Prahmana et al., 2023; Prahmana & Istiandaru, 2021; Risdiyanti & Prahmana, 2020). Additionally, Realistic Mathematics Education (RME) offers another approach that helps students connect mathematics with real-life situations (Prahmana et al., 2020; Risdiyanti et al., 2024). Combining these two approaches—Ethnomathematics (Rosa et al., 2017) and RME (Van den Heuvel-Panhuizen & Drijvers, 2020)—holds promise for enhancing students' mathematical learning in novel ways. This study integrates these approaches into Ethno-RME, aiming to enable students to grasp and apply mathematical concepts within contexts that resonate with their everyday lives (Prahmana, 2022; Prahmana et al., 2023).

Building on this foundation, this research aims to develop an e-module focused on number pattern materials, employing an Ethno-Realistic Mathematics Education (Ethno-RME) approach to enhance students' problem-solving abilities. By integrating cultural elements such as Yogyakarta batik motifs, the study aims to bridge the gap between traditional and contemporary educational practices.

Anticipated outcomes include providing new insights into mathematics education in Indonesia and offering innovative, culturally relevant, and effective solutions to cater to the diverse needs of students in the digital age. This approach not only emphasizes the practical application of mathematical concepts but also promotes a deeper understanding and appreciation of Indonesia's cultural heritage within the context of mathematics learning.

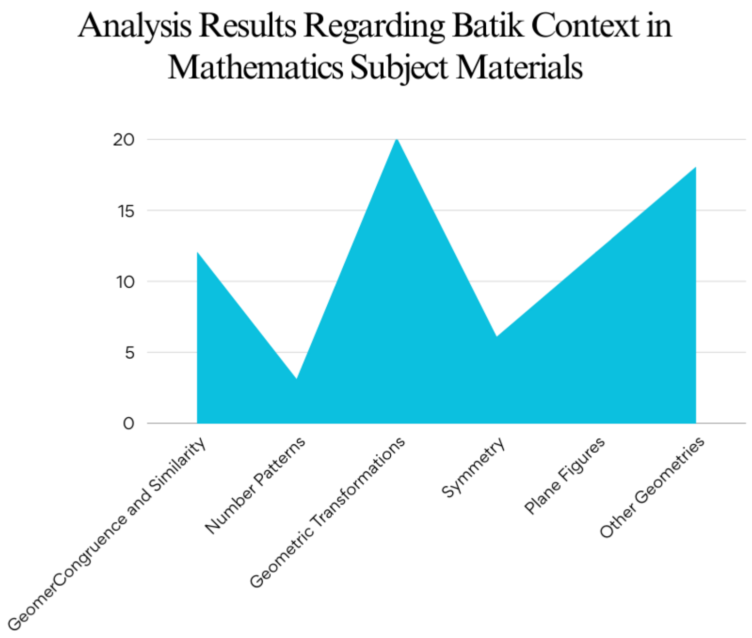

Figure 3. Analysis results regarding batik context in mathematics subject materials

Methods

This research adopts a design research approach of the development type, focusing on creating an electronic module grounded in Ethno-Realistic Mathematics Education (Ethno-RME). The developmental process in this study consists of two main stages: the Preliminary Evaluation stage and the Formative Evaluation stage, as depicted in Figure 4 (Tessmer, 2013).

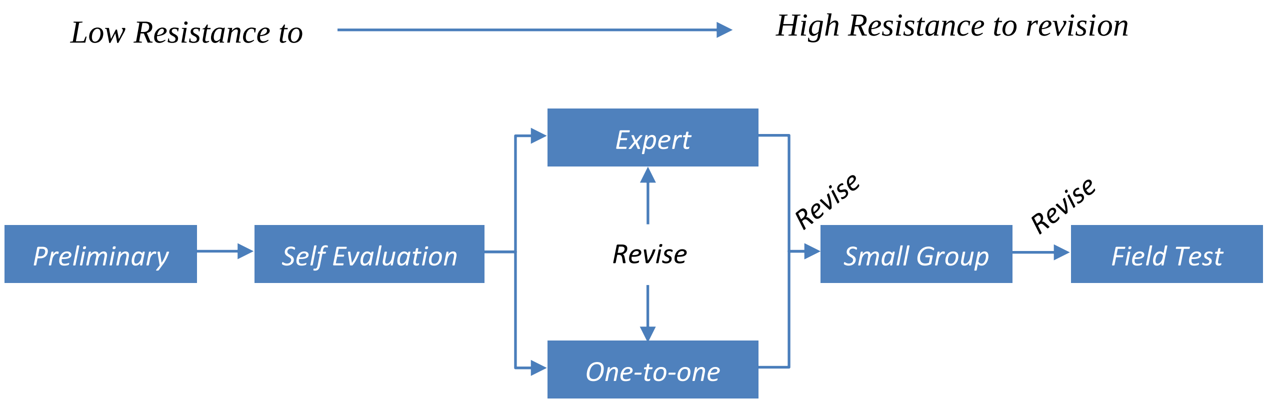

Figure 2. Formative evaluation design

This research was conducted during the academic year 2023/2024 at SMP Muhammadiyah 6 Yogyakarta, involving students from classes VIII A and VIII C. The study employed a combination of non-test and test data collection techniques. Non-test methods included interviews, observations, surveys, and documentation to assess the validity and practicality of the Ethno-RME-based e-module and to support the research data. Test techniques comprised pretests and posttests administered to measure the potential impact of utilizing the Ethno-RME-based e-module on enhancing students' problem-solving abilities.

The instruments utilized for data collection included expert validation sheets for content and media, student response surveys, pretest questions, and posttest questions. Expert validation sheets were employed to gather validity assessment data for the e-module, ensuring the content and media were robust and aligned with educational objectives. Student response surveys were conducted to gather feedback from students regarding their experiences with the e-module. Pretest and posttest questions were administered to assess the impact of the e-module on improving students' problem-solving abilities, providing quantitative data for evaluation and comparison.

The assessment criteria for product quality were deemed valid and practical if the average scores met or exceeded the threshold for good quality (Tanujaya et al., 2022; Cheung et al., 2024). To evaluate the impact of the product, pretest and posttest scores measuring students' problem-solving abilities were analyzed using T-Tests and N-Gain Tests. During the preliminary evaluation phase, issues were analyzed, and solutions designed based on identified problems. Subsequently, in the formative evaluation phase, product quality was assessed through expert reviews, one-to-one sessions, small group discussions, and field tests. Evaluation of product quality utilized a Likert Scale (1 to 5) on assessment sheets (Tanujaya et al., 2022).

Furthermore, the developed e-module was considered practical if student response assessments indicated at least a "good" level. Walkthrough data from expert reviews, one-to-one sessions, and small group discussions provided feedback and suggestions on the e-module. Analysis of product quality assessment instruments and student responses guided revisions to ensure the e-module achieved validity and practicality. The potential impact of the e-module on students' problem-solving abilities was assessed through a problem-solving ability test.

Results

This research is structured into two key stages: the preliminary stage and the formative evaluation stage. The preliminary stage focuses on identifying initial issues in mathematics education, particularly concerning students' problem-solving abilities, and designing solutions. It employs non-test techniques like interviews, observations, surveys, and documentation to gather data and inform the development of an Ethno-RME-based e-module integrating cultural contexts such as Yogyakarta batik.

In contrast, the formative evaluation stage assesses and refines the e-module's quality through expert reviews, one-to-one sessions, small group discussions, and field tests. Evaluation criteria include expert validation sheets, Likert Scale assessments, and student response surveys to ensure the e-module meets standards of validity, practicality, and educational effectiveness. Pretest and posttest assessments measure the e-module's impact on enhancing students' problem-solving abilities, ultimately aiming to advance understanding and implementation of Ethno-RME approaches in mathematics education.

Preliminary evaluation stage

The stage commences with analysis activities followed by product design based on identified needs. During the analysis phase, the researcher undertakes curriculum, student characteristic, and instructional material analyses. These activities rely on interviews with teachers and student observation sheets. The needs analysis identified key aspects pertinent to effective instructional strategy at SMP Muhammadiyah 6 Yogyakarta.

Firstly, the school implements the Merdeka curriculum, emphasizing diverse extracurricular learning to optimize content delivery, allowing ample time for concept comprehension and skill reinforcement in line with institutional educational goals. Secondly, current modules used by teachers inadequately assess students' mathematical problem-solving abilities, necessitating more comprehensive instructional materials to enhance these critical skills. Addressing this shortfall underscores a focus on improving students' mathematical problem-solving competencies. Moreover, cultural integration in mathematics teaching remains underdeveloped among teachers, highlighting the need for curricular enrichment to enhance relevance and engagement. Thus, there is a clear need for instructional materials fostering student-centered learning to facilitate independent learning processes.

Additionally, teachers seek materials promoting active student involvement, thereby shifting from traditional teacher-centric approaches to student-centered learning for enhanced engagement and comprehension. Lastly, students require accessible, smartphone-compatible instructional materials to support autonomous learning, with Ethno-Realistic Mathematics Education (Ethno-RME) e-modules identified as a fitting solution. These modules offer culturally relevant and engaging tools aligning with contemporary digital learning environments. Subsequently, observations and consultations with mathematics teachers led to the selection of eighth-grade students from classes VIII C and VIII A at SMP Muhammadiyah 6 Yogyakarta for one-on-one and small group testing, totaling 22 students across varied skill levels. Following these selections, the researcher devised solutions addressing identified needs.

The researcher developed an Ethno-Realistic Mathematics Education (Ethno-RME)-based e-module aimed at enhancing eighth-grade students' mathematical problem-solving skills, particularly focusing on number pattern materials aligned with the Merdeka curriculum. Additionally, research instruments, including expert validation sheets for content and media, student response surveys, and pretest/posttest assessments, were created to ensure instructional efficacy and relevance, while gathering comprehensive feedback from experts and students alike.

Formative evaluation stage

This stage comprises five major phases: self-evaluation, expert review, one-to-one, small group, and field test.

Self-evaluation

During this stage, the researcher conducted a self-evaluation of the e-module and research instruments, assessing content, structure, and language aspects. Based on the self-evaluation results, few changes were made from the previous version. Enhancements focused on refining the cover design and symbols used within the e-module. The outcome of this self-evaluation phase is termed prototype 1, comprising an e-module on number patterns utilizing the Ethno-RME approach, expert validation sheets for content and media, student response instruments, and problem-solving assessment questions.

Expert review

In the expert review stage, activities commenced with the validation of research instruments, starting with Prototype 1. The validated instruments included both non-test and test components. Non-test instruments validated comprised expert validation sheets for content, expert validation sheets for media, and student response questionnaires. Expert 1, a Mathematics Education lecturer at a private university in Yogyakarta, Indonesia, participated as a reviewer in a face-to-face validation process for these instruments. Review findings for the expert validation sheets for content and media, and student response questionnaires indicated their validity in terms of content, construction, and linguistic or cultural appropriateness. It was concluded that these instruments are suitable for use with minor revisions.

Meanwhile, the validation of Prototype 1 of the e-module involved assessment by two content and media experts. The expert reviewers included:

1. Expert 2, a Mathematics Education lecturer at a private university in Yogyakarta, Indonesia. The validity testing was conducted face-to-face on March 21, 2024, and online (Google Meet) on March 24, 2024.
2. Expert 3, an Ethnomathematics expert and Mathematics Education lecturer at a private university in Medan, Indonesia. The review was conducted via mail on April 25, 2024.
3. Expert 4, a Mathematics Education lecturer at a private university in Yogyakarta, Indonesia. The review was conducted via mail on April 1 and May 5, 2024.
4. Expert 5, a mathematics teacher for eighth grade at a Junior High School in Yogyakarta, Indonesia. The review was conducted via mail on April 29, 2024.

Overall, the results of the expert review assessment criteria for product quality validation are summarized in Tables 1 and 2.

Table 1. Results of the product quality criteria questionnaire by content experts

No	Validator	Score	Criteria
1	Expert 2	104	Good
2	Expert 3	100	Good
	Total Score	**204**	
	Average Score	**102**	**Good**

Table 1 explains about the assessment scores from content experts indicate an average score of 102, affirming that the Ethno-RME-based e-module meets the criteria for strong content expert assessment. Consequently, the developed Ethno-RME-based e-module is considered valid.

On the other hand, during the validation process of the Ethno-RME-based e-module, two content experts were tasked with evaluating 26 statements. The experts concurred on 16 of these statements, yielding an inter-rater reliability (IRR) value of 31% (Cole, 2023). This percentage indicates a slight to fair level of agreement between the content experts, suggesting variability in their ratings (Landis & Koch, 1977). The slight to fair IRR may reflect inconsistencies in how the evaluation criteria were interpreted, potentially due to differing expectations or subjective biases (Belur et al., 2021). This finding underscores the need for clearer and more standardized evaluation criteria to ensure consistent application.

This agreement level could also affect the perceived validity of the e-module's content. To address these issues, it may be necessary to revisit the evaluation process, clarify the criteria, and consider involving additional experts to enhance the reliability and accuracy of the validation. Detailed comments and suggestions from the content experts' validation results can be found in Table 2.

Table 2. Comments or suggestions from content experts

No	Comments and Suggestions
1	There are geometric elements on the e-module cover that are unrelated to the content.
2	The Learning Outcomes for Number Patterns are not explicitly stated in Phase D Number Elements.
3	The Concept Map, particularly its content arrangement, still needs improvement.
4	The introduction containing Leonardo da Pisa's biography is not relevant to the number patterns material because Fibonacci number patterns are not discussed in this e-module.
5	The introduction as the beginning of the learning does not show the connection between the Yogyakarta Batik context and the number patterns material.
6	Conducted on example problems that are not related to the context of Yogyakarta Batik.

Here are the results of the media expert validation calculations as seen in Table 3.

Table 3. Results of the media expert questionnaire on product quality criteria

No	Validator	Score	Criteria
1	Expert 3	78	Very Good
2	Expert 4	79	Very Good
	Total Score	**157**	
	Average Score	**78.5**	**Very Good**

Based on the assessment scores in Table 3, the average score from media experts is 78.5, meeting the criteria for excellence. Therefore, the Ethno-RME-based e-module developed is considered valid based on the media expert validation.

On the other hand, during the validation process of the Ethno-RME-based e-module, two learning media experts were asked to evaluate 17 statements. Of these, the experts agreed on 8 statements, resulting in an inter-rater reliability (IRR) value of 24% (Cole, 2023). This percentage reflects a slight level of agreement between the two experts (Landis & Koch, 1977), as they concurred on only 24% of the total statements. This IRR level suggests inconsistency in their evaluations, which may stem from differing interpretations of the evaluation criteria, ambiguity in the statements, or subjective biases (Belur et al., 2021). Consequently, an IRR value of 24% highlights the need for more consistent and aligned evaluations in the validation process to ensure that the assessment of the Ethno-RME-based e-module is both reliable and credible.

Furthermore, detailed comments and suggestions from the media experts' validation results can be found in Table 4.

Table 4. Comments or suggestions from media experts

No	Comments and Suggestions
1	Review the number pattern material to include it in the learning outcomes of number or algebra elements.
2	Include indicators of problem-solving abilities.
3	Review the learning objectives sequence.
4	Review sequences and series.
5	The connection between Yogyakarta batik context and number pattern material is not yet apparent.

Following the validation process by content and media experts, the researcher diligently incorporated feedback to enhance the Ethno-RME-based e-module. Figure 5 depicts several improvements implemented, reflecting adjustments aimed at refining content clarity and media effectiveness. Feedback from content experts focused on strengthening conceptual depth and alignment with educational objectives, leading to revisions that clarified instructional materials and enriched learning experiences. Meanwhile, insights from media experts guided enhancements in visual design and interactive features, ensuring the e-module's accessibility and engagement. These iterative improvements underscored the module's evolution towards meeting stringent validation criteria, affirming its validity and readiness for subsequent testing phases.

Before Revision **After Revision**

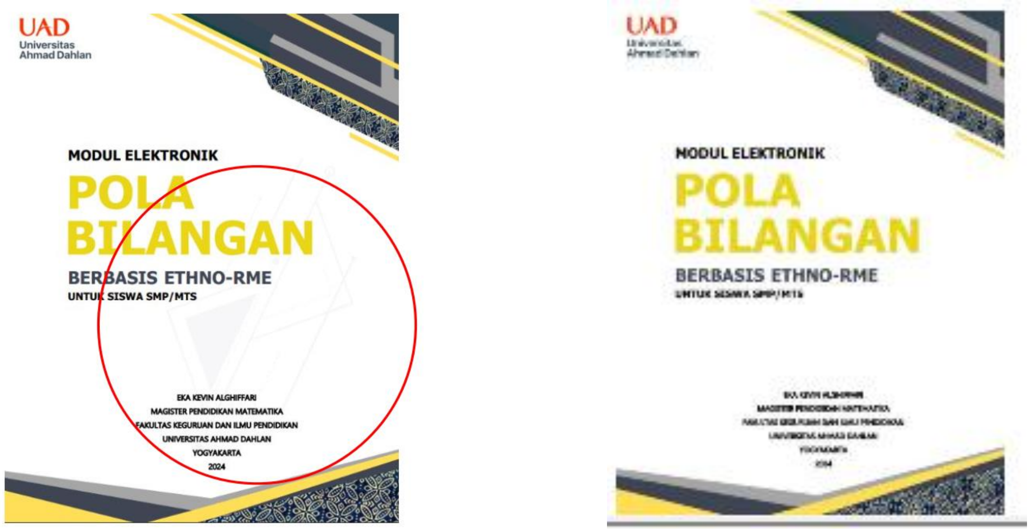

Figure 5. E-Module cover revision

The learning outcomes for Number Patterns were initially not explicitly stated in Phase D Number Elements. Subsequently, a revision was made, replacing it with Phase D Algebra

Elements, as illustrated in Figure 6. This adjustment aims to clarify and align the learning objectives more closely with algebraic concepts, ensuring coherence and relevance in educational content delivery.

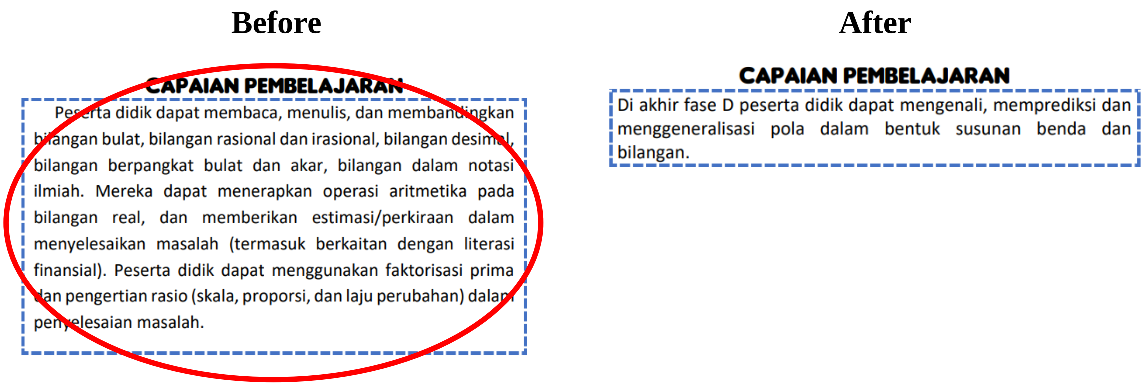

Figure 6. Revision of learning outcomes

In Prototype 1, the e-module featured a concept map with content arrangement that required improvement. Consequently, the concept map underwent revision, resulting in the updated version displayed in Figure 7. This revision aimed to enhance the clarity and coherence of content organization within the concept map, ensuring it effectively supports learning and understanding of the module's key concepts.

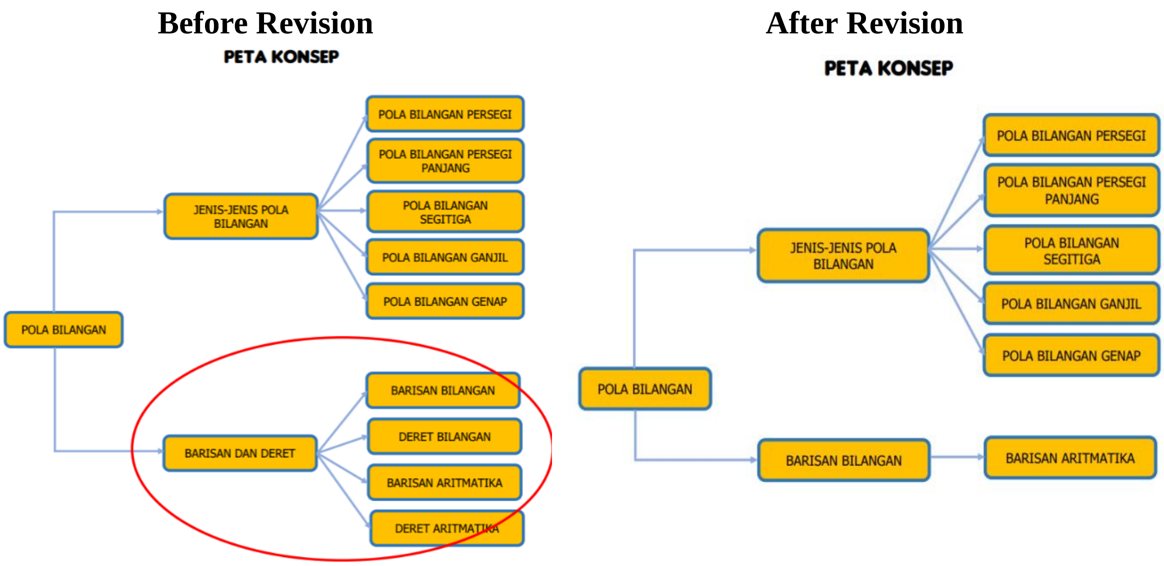

Figure 7. Revision to the concept map

Furthermore, additional revisions were made to the Concept Map to further refine the content arrangement. In addition, revisions were implemented in the Introduction section, where the initial inclusion of Leonardo da Pisa's biography was unrelated to the e-module's focus on number patterns, as Fibonacci number patterns are not discussed. Moreover, the original introduction did not effectively establish a clear connection between the Yogyakarta Batik context and the material on number patterns. The revised introduction, now visible in Figure 8, addresses these issues by enhancing coherence and relevance at the outset of the learning experience.

Before Revision **After Revision**

Figure 8. The revision of introduction section

Further revisions were undertaken in the example problems section, aiming to align them more closely with the Yogyakarta Batik context. The updated example problems are illustrated in Figure 9, reflecting adjustments that enhance relevance and contextual connection within the e-module's instructional material.

Before Revision **After Revision**

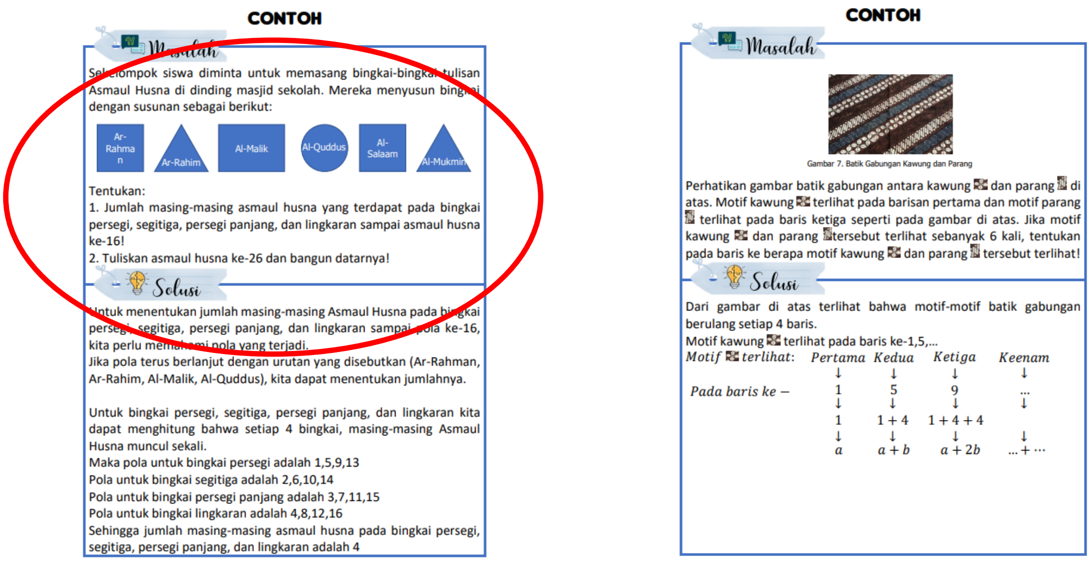

Figure 9. Revision of example problems

One-to-one

The product underwent testing involving three students from class VIII C at SMP Muhammadiyah 6 Yogyakarta, selected for their diverse cognitive abilities. During this phase, students engaged with exercises and provided feedback on Prototype 1. The primary objective was for the researcher to observe students' interactions with the e-module, noting their challenges and responses. Detailed feedback and suggestions gathered from this one-to-one testing stage are documented in Table 5.

Table 5. Suggestions and comments one to one

No	Suggestions and Comments
1	The batik image display should be enlarged for better visibility.
2	The language used should be simpler to make it easier to understand.

The feedback and suggestions gathered from the one-to-one testing stage underwent revision; however, the revisions did not lead to significant changes.

Small group

The suggestions and feedback from the One-to-One stage were incorporated into revisions, leading to the development of Prototype 2. Prototype 2 underwent testing with six students from class VIII C at SMP Muhammadiyah Yogyakarta, who were not previously involved in the research, on April 29, 2024. The Small Group stage aimed to assess the e-module's readability and gather feedback from the students before proceeding to the Field Test stage. The results of the student response questionnaire from the Small Group stage are presented in Figure 10, detailing the insights and responses obtained during this phase of evaluation.

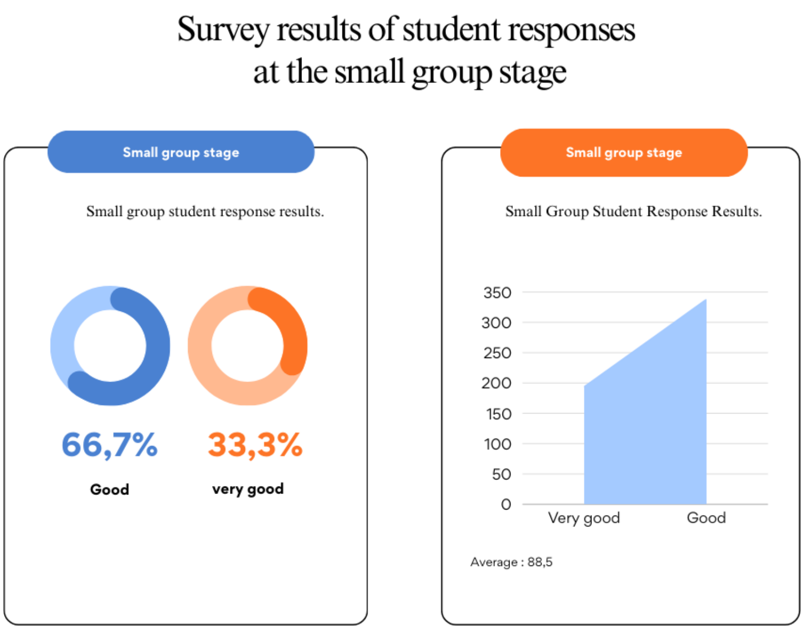

Figure 10. Results of student response questionnaire

In Figure 10, an average score of 88.5 was achieved, indicating that the practicality of using the e-module falls within the "Good" criteria. In addition to evaluating practicality, the researcher analyzed feedback and comments from students as potential improvement material for Prototype 2 before its implementation in the field test stage. Detailed student feedback and suggestions are documented in Table 6, providing insights into areas for refinement and enhancement based on student perspectives and experiences during the Small Group testing phase.

Table 6. Suggestions and comments small group

No	Suggestions and Comments
1	The context of Yogyakarta batik helps me understand the topic of Number Patterns.
2	The language used is difficult to understand.
3	The electronic module is interesting to study.

Based on Table 6, revisions were made to the language used in the e-module by the researcher. An example of this revision can be viewed in Figure 11.

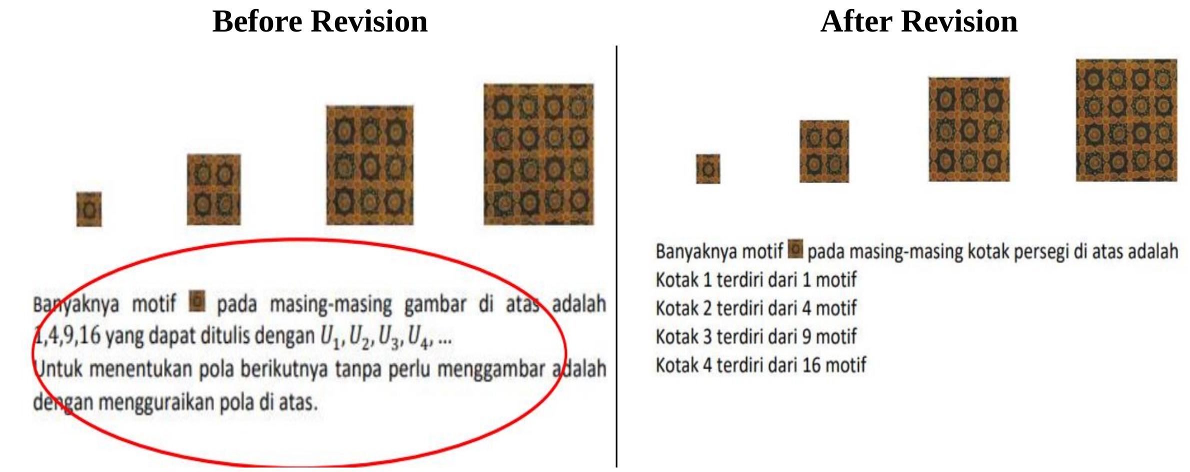

Figure 11. Results of revision to the language in the e-module

Field test

In the iterative development process of the Ethno-RME-based e-module, feedback and comments from the Small Group session were crucial in refining the prototype, resulting in Prototype 3. This version was then subjected to rigorous testing during the Field Test stage with 22 students from class VIII A at SMP Muhammadiyah 6 Yogyakarta, who were participants in the study. The Field Test was structured across three sessions: the first session on April 30, 2024, involved administering a Pre-Test to gauge students' initial understanding; the second session on May 7, 2024, focused on the active learning process using the revised module; and the third session on May 8, 2024, concluded with a Post-Test to assess learning outcomes, followed by completion of the student response questionnaire to gather qualitative feedback on the module's effectiveness and usability.

Figure 12 presents the results of the student response questionnaire from the Field Test, providing insights into students' perceptions and experiences with Prototype 3. This feedback serves as valuable data for further refinement of the e-module, highlighting areas where adjustments may be necessary to enhance educational efficacy and user engagement. The iterative nature of this testing and feedback process ensures that the Ethno-RME-based e-module aligns closely with educational goals and meets the needs of students, paving the way for its potential implementation in broader educational contexts with confidence in its pedagogical effectiveness.

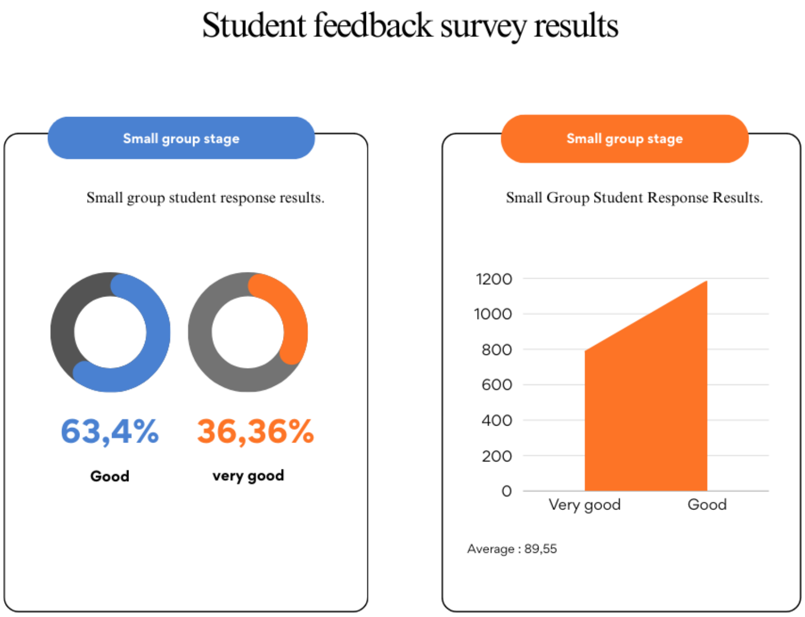

Figure 12. Results of student feedback survey results

In this assessment, the average score of 89.55 indicates that the level of mathematical problem-solving ability meets the "Good" criteria. This finding suggests that both the pre-test and post-test results demonstrate improvement across various indicators of mathematical problem-solving ability. Consequently, these outcomes suggest a positive impact of the e-module on enhancing students' problem-solving skills. The results underscore the potential effectiveness of the Ethno-RME-based e-module in fostering improved mathematical understanding and problem-solving capabilities among students, validating its value as an educational tool within the classroom setting.

Discussion

The research findings demonstrate that the Ethno-RME-based e-module developed adheres to criteria of validity, practicality, and potential impact on enhancing students' mathematical problem-solving abilities. The development process followed a Design Research model, employing a Development Studies framework comprising two principal stages: Preliminary and Formative Evaluation.

During the Preliminary stage, which encompassed the analysis phase, it was identified that the school's curriculum aligns with the Independent Curriculum, known as Kurikulum Merdeka, mandated by the government. This stage also revealed a significant gap in students' problem-solving skills, underscoring the absence of tailored e-modules addressing this critical area. Notably, the research introduced a novel approach by incorporating minimal use of batik contexts in ethnomathematical studies focused on number patterns, aiming to enrich students' engagement and contextual understanding.

These initial findings served as foundational insights for the subsequent stages of e-module development. The Formative Evaluation stage involved iterative revisions based on evaluation outcomes at each step, culminating in the refinement of the Ethno-RME-based e-module specifically tailored to enhance students' proficiency in mathematical problem-solving. This iterative approach ensures that the e-module not only meets educational standards but also integrates culturally relevant elements to optimize learning outcomes in mathematics education.

Following the analysis results, the research proceeded to the e-module design stage, designated as Prototype I. The Formative Evaluation phase encompassed three key stages: self-evaluation, prototype development involving expert review, one-to-one sessions, and small group testing, and finally, field testing. Prototype I was initially evaluated through self-assessment by the researcher, resulting in an Ethno-RME-based e-module focused on number patterns. This version included quality assessment sheets validated by experts and test questions designed to gauge the e-module's impact on students' problem-solving abilities.

Subsequently, Prototype I underwent rigorous evaluation through expert reviews and one-to-one sessions. Feedback from these evaluations informed iterative improvements to the e-module, addressing insights garnered from both experts and student feedback. Based on evaluation outcomes indicating adherence to "Good" criteria for content validity and "Very Good" criteria for media quality, Prototype I was refined and designated as Prototype 2. These evaluations underscored the e-module's robustness in delivering content and its effectiveness in engaging students through high-quality media elements, affirming its readiness for further testing and refinement.

After successful validation in the expert review and one-to-one stages, Prototype 2 underwent practicality testing using student response questionnaires in small groups. Six students with varying cognitive abilities participated in this phase, engaging with the e-module to study and solve problems. Subsequently, students provided valuable feedback and comments through the questionnaires, leading to evaluations that met the minimum "Good" criteria for practicality in the small group trial stage. These outcomes validated the e-module's usability and effectiveness in a controlled learning environment.

Following revisions based on small group feedback, the refined version was designated as Prototype 3, recognized for both its validity and practicality. Prototype 3 progressed to field testing among 22 students from class VIII A at SMP Muhammadiyah 6 Yogyakarta, conducted over three sessions. Initially, students completed a pre-test to assess their baseline problem-solving abilities. After engaging in learning activities facilitated by Prototype 3, students then participated in post-tests and completed student response questionnaires. Results from the field test questionnaires met the "Good" criteria, affirming the e-module's practical application within classroom settings. Moreover, the problem-solving ability tests demonstrated improvement, indicating the e-module's potential to enhance students' mathematical problem-solving skills through structured, culturally relevant learning experiences.

The e-module's content was meticulously structured following the Ethno-Realistic Mathematics Education (Ethno-RME) approach steps, as outlined by Prahmana et al. (2023), and grounded in indicators of problem-solving abilities proposed by Hendriana et al. (2017). The integration of Ethno-RME into the assessment of the e-module's impact on problem-solving abilities is rooted in their intrinsic correlation (Tumangger et al., 2024). Ethno-RME's instructional framework empowers students not only to grasp mathematical concepts theoretically but also to cultivate practical problem-solving skills within contextualized settings (Ramadhani et al., 2023).

Ethno-RME's methodology substantiates its potential influence on problem-solving capabilities. By initiating problem-solving tasks with culturally relevant contexts, Ethno-RME ensures the availability of authentic and concrete data that facilitates students in identifying pertinent information essential for solving mathematical problems (Rahmadani et al., 2023). Furthermore, students engage in constructing mathematical models derived from problem scenarios and employ them in solution strategies by exploring information embedded in familiar cultural contexts (Singgih, 2023). This approach empowers students to select and apply effective strategies—both mathematical and non-mathematical—to resolve challenges, leveraging insights gained from mathematical discoveries situated within cultural contexts (Lubis et al., 2023; Caraan et al., 2023). Ethno-RME further supports students in interpreting results rigorously and verifying the accuracy of their solutions, thereby fostering a profound comprehension of mathematical concepts through exploration and application within familiar environments (Prahmana, 2022). Ultimately, the idea of Ethno-RME encourages students to apply mathematics meaningfully, facilitating critical reflection that bridges mathematical knowledge with real-world contexts, supported by Turner et al. (2009) and is further evidenced by Nurnaningsih et al. (2024), who demonstrated the effectiveness of integrating Ethno-RME with digital technology to enhance students' understanding of systems of linear equations through the Mangkujo Math Trail.

Conclusion

The Ethno-RME-based e-module focusing on number patterns designed for eighth-grade students has exhibited robust validation, practicality, and promising efficacy in enhancing students' mathematical problem-solving skills. The research findings reveal that content expert reviews, conducted by Expert Reviews 1 and 2, yielded an average score of 102, indicating a "Good" categorization. Similarly, evaluations by media experts in Expert Reviews 3 and 4 achieved an average score of 78.5, categorized as "Very Good". Moreover, student responses during the small group trial involving six eighth-grade students from Class VIII C averaged 88.5, reflecting another "Good" rating. Likewise, in the field test trial with 22 eighth-grade students from Class VIII A, student responses averaged 89.55, reinforcing its practicality and positive reception. Therefore, based on comprehensive student feedback from both trials, the e-module is acknowledged for its practical utility and favorable reception among students.

The potential impact of the e-module on problem-solving abilities was clearly demonstrated through the results of problem-solving tests conducted during the field test, revealing notable advancements in mathematical learning through a problem-solving approach. Significant improvements were discerned upon comparing the average scores from pre-test to post-test assessments. Therefore, it is concluded that the e-module shows promise in enhancing students' proficiency in mathematical problem-solving skills.

Looking ahead, it is recommended to undertake further studies with larger student cohorts to validate and refine the effectiveness of the e-module. The current study represents an initial exploratory phase in the development of the e-module, underscoring the need for subsequent research to substantiate its impact across broader student populations. In addition, the validation calculations using IRR indicated a need for improvement in reliability, as the IRR values from both media and content experts reveal a slight to fair level of agreement for the developed e-module. This suggests a need to revisit the evaluation process, clarify the criteria, and consider involving additional experts to enhance the reliability and accuracy of the validation. This approach will provide more robust evidence regarding its efficacy and applicability in educational settings.

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Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this manuscript. In addition, the authors have completed the ethical issues, including plagiarism, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies.

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Author Contributions

Eka Kevin Alghiffari: Conceptualization, writing - original draft, editing, and visualization; **Rully Charitas Indra Prahmana:** writing - original draft, Writing - review & editing, formal analysis, and methodology; **Brian Evans:** Validation and supervision.

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