STEM-PBL Based E-Module with Jambi Context: Development Research to Improve Students' 4C Skills

Feri Tiona Pasaribu[1*], Tria Gustiningsi[2], Isnania[3], Leizel P. Ariem Concepcion[4]

[1*,2]Department of Mathematics Education, Universitas Jambi
[3]Department of Elementary School Teacher Education, Universitas Jambi
Jalan Jambi-Ma. Bulian KM.15, Mendalo Indah, Kec. Jambi Luar Kota, Kab. Muaro Jambi
[1*]_feri.tiona@unja.ac.id_; [2]_triagustingsi@unja.ac.id_ ; [3]_isnania@unja.ac.id_

[4]Elementary Education Department, Mariano Marcos State University
City of Batac, Ilocos Norte 2906, Philippines
[4]_laconcepcion@mmsu.edu.ph_

Abstrak

Penelitian ini bertujuan untuk merancang dan mengevaluasi modul e-learning berbasis STEM-PBL yang terintegrasi dengan konteks budaya Jambi guna meningkatkan keterampilan 4C siswa. Penelitian ini menggunakan jenis penelitian research and development (R&D) dengan model ADDIE. Peserta penelitian terdiri dari 26 siswa dan 1 guru matematika dari kelas VII.1 MTs N 3 Batang Hari. Alat penelitian meliputi tes keterampilan 4C, lembar validasi ahli, kuesioner tanggapan guru dan siswa, serta lembar observasi. Validasi materi dan desain oleh ahli menghasilkan skor 92% dan 94%, masing-masing, dengan skor validitas keseluruhan 93%, menunjukkan bahwa e-module memenuhi standar kualitas akademik dan pedagogis. Dalam hal kepraktisan, uji coba individu memperoleh skor 92%, sementara uji coba kelompok kecil mendapatkan 89%, dengan skor kepraktisan rata-rata 90,5%, menunjukkan bahwa e-modul mudah digunakan dan mendukung pembelajaran yang efektif. Pengamatan di kelas menunjukkan skor 88,6%, menunjukkan bahwa implementasi e-modul sesuai dengan sintaks pembelajaran STEM-PBL. Selain itu, siswa mencapai skor n-gain rata-rata 0,78 pada tes keterampilan 4C. Secara keseluruhan, hasil penelitian menunjukkan bahwa e-module yang dikembangkan valid dan praktis sebagai sumber belajar. Integrasi STEM-PBL dengan pedagogi yang relevan secara budaya dalam konteks pendidikan Indonesia menawarkan pendekatan yang menjanjikan untuk meningkatkan keterampilan 4C siswa.
Kata Kunci: *STEM-PBL; E-Modul; Kemampuan 4C; Konteks Jambi.*

Abstract

This study aimed to design and evaluate a STEM-PBL-based e-module integrated with the cultural context of Jambi to improve students' 4C skills. The study employed a research and development (R&D) approach using the ADDIE model. The participants consisted of 26 students and 1 mathematics teachers from class VII.1 MTs N 3 Batang Hari. The research instruments included a 4C skills test, expert validation sheets, teacher and student response questionnaire, and observation sheets. The material and design expert validations yielded scores of 92% and 94%, respectively, resulting in an overall validity score of 93%, indicating that the e-module meets academic and pedagogical quality standards. In terms of practicality, the individual trial achieved a score of 92%, while the small-group trial obtained 89%, with an average practicality score of 90.5%, suggesting that the e-module is easy to use and supports effective learning. Classroom observations showed a score of 88.6%, indicating that the implementation of the e-module aligns well with the STEM-PBL learning syntax. Furthermore, students achieved an average n-gain score of 0.78 on the 4C skills test. Overall, the findings indicate that the developed e-module is valid and practical as a learning resource. Integrating STEM-PBL with culturally relevant pedagogy in the Indonesian educational context offers a promising approach to enhancing students' 4C skills.
Keywords: STEM-PBL; E-Module; 4C Skills; Jambi Context.

I. INTRODUCTION

Education plays a strategic role in the development of quality human resources because it contributes directly to individuals' thinking, problem-solving, and innovation skills (Hairunnisa et al., 2023; Hysa & Jakupi, 2023). In the context of formal education, mathematics is a fundamental subject because it plays an important role in building students' logical, analytical, and problem-solving skills (Rosyidi, 2018). However, the demands of 21st-century learning require mathematics education to not only focus on mastering concepts but also on strengthening the 4C skills (critical thinking, creativity, communication, and collaboration), which are essential competencies in the era of globalization and the 4.0 industrial revolution (Jihan Nurhamidah & Arladia Hafsya, 2024; Nurhayati et al., 2024).

Figure 1. Components skills 21st century 4C.

The 4C skills (see Figure 1) are considered important to be applied to students from an early age because they can address the complex challenges of this century, namely education facing rapid changes due to globalization and the 4.0 industrial revolution, which requires the ability to think analytically, innovate, and solve problems creatively (Jihan Nurhamidah & Arladia Hafsya, 2024; Nurhayati et al.,

2024). The 4C components that students must possess are critical thinking, creative thinking, communication, and collaboration. These four skills are seen as key competencies that students must master in order to succeed and adapt in today's highly dynamic global and digital era (Nurhayati et al., 2024). Critical thinking is the process of seeking correct conclusions through problem solving by considering various information and arguments (Haviz, 2009). Creativity is the ability to generate new and innovative ideas, as well as to think outside the box in solving various challenges (Nurhayati et al., 2024). Communication is the skill of conveying ideas, thoughts, and information clearly and effectively, both verbally and in writing, as well as listening well. Collaboration is the ability to work effectively with others in a team or group, respect other opinions, and share responsibilities to achieve common goals (Lestari & Hindun, 2023).

With the development of technology, innovation in digital-based learning media has become an inevitable necessity. One form of such innovation is the E-Module, which is capable of providing more interactive, visual, and flexible learning through the integration of images, videos, and digital activities (Cynthia et al., 2023; Isnania et al., 2025; Saparuddin, 2022). A number of studies show that E-Modules, especially those containing ethnomathematics elements, have been proven effective in improving student learning outcomes and engagement (Madu et al., 2025). However, the implementation of E-Modules in mathematics learning still faces challenges, particularly related to the low critical thinking and creativity skills of

junior high school students as part of the 4C skills that have not been optimally developed.
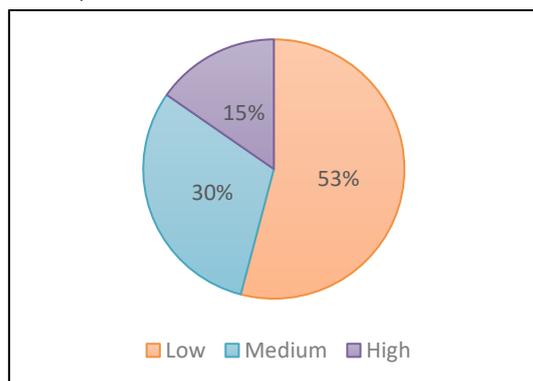

Figure 2. Student Critical Thinking Abilities.

Preliminary findings (see Figure 2) obtained during the pre-research stage at MTs N 3 Batang Hari indicate that the critical thinking skills of seventh-grade students remain at a low level. Based on the results of an initial diagnostic test conducted prior to the main study, students achieved an average score of 58, with more than half of the students categorized in the low-level group. In addition, preliminary classroom observations and informal interviews with mathematics teachers revealed that other 4C skills were also insufficiently developed.

Observational data showed that most students demonstrated low levels of communication skills, as indicated by limited participation in discussions and difficulties in articulating mathematical ideas, as well as weak collaboration skills, reflected in minimal role-sharing and ineffective cooperation during group activities. These conditions are closely related to the dominant use of conventional and monotonous teaching materials, which provide limited opportunities for interaction, idea exploration, and meaningful problem-solving. Therefore,

these preliminary findings highlight the need for innovative learning materials that can actively engage students and systematically support the development of students' 4C skills.

Therefore, learning must begin with real problems that are relevant to the students' circumstances. To address these problems, integrating Problem-Based Learning (PBL) with the STEM (Science, Technology, Engineering, Mathematics) approach is a promising strategy. PBL emphasizes real-world problem-based learning and is student-centered, encouraging them to think critically and creatively in solving problems (Endang Indarini, 2024; Fausih & Danang, 2015; Nabilah et al., 2025; Nurlaela & Imami, 2022; Saputri et al., 2025; Syaharani et al., 2022). Meanwhile, the STEM approach connects mathematical concepts with science, technology, and engineering, making learning contextual and relevant to everyday life (Hacioglu & Gulhan, 2021; Handayani et al., 2021; Margaretha et al., 2024). Previous studies have shown that the integration of PBL and STEM significantly improves students' critical thinking, creativity, communication, and collaboration skills (Khoirunnissa et al., 2024; Pasaribu, Gustiningsi, Ariefah, et al., 2025; Purnamasari et al., 2020; Walipah et al., 2024).

Previous studies have confirmed that STEM-PBL-based E-Modules are valid, practical, and effective in improving students' critical thinking skills compared to conventional teaching materials (Frisky Rapika Dwi et al., 2024; Kurniati et al., 2021; Nia et al., 2022; Pasaribu, Gustiningsi, Ariefah, et al., 2025; Pujiono et al., 2024;

Rohmatulloh et al., 2023). Furthermore, the integration of ethno-STEM elements in E-Modules has also been proven to strengthen students' conceptual understanding and critical thinking skills in a contextual manner (Izzania et al., 2024). However, the development of STEM-PBL E-Modules that specifically integrate the local cultural context of Jambi to strengthen junior high school students' 4C skills is still relatively limited.

STEM-PBL-based e-modules enable interactive and engaging material delivery that can integrate the local context or culture of Jambi. The use of local cultural contexts is in line with contextual learning, which emphasizes the connection between material and students' real-life experiences, thereby enhancing conceptual understanding and higher-order thinking skills (Jonsson et al., 2020; Susanty et al., 2023; Wulandari et al., 2024). Jambi's local wisdom, such as Rumah Kajang Lako and the Batanghari River ecosystem, has great potential as an authentic context in STEM learning that is close to students' lives (Ajayan et al., 2025; Kamid & Ramalisa, 2019). This approach not only improves 4C skills but also fosters students' learning motivation, creativity, and cultural awareness, making learning more meaningful and relevant (Izzania et al., 2024; Nurhayati et al., 2024; Thornhill-miller et al., 2025).

Based on this description, this study focuses on the development of a STEM-PBL-based E-Module with a Jambi cultural context as a design study to improve students' 4C abilities, particularly in mathematics learning. This approach is expected to not only improve the quality of learning and students' 21st-century skills but also strengthen the relevance of mathematics learning through the meaningful integration of local cultural contexts.

II. Method

This study employed the ADDIE instructional design model: Analysis, Design, Development, Implementation, and Evaluation to develop a STEM-PBL based e-module intended to enhance junior high school students' 4C competencies. The ADDIE framework is widely recognized for its structured, iterative, and learner-centered approach, making it suitable for developing digital instructional materials in contemporary educational research (Lestari & Hindun, 2023; Robert Maribe, 2009). The research was conducted using a research and development (R&D) methodology, where the ADDIE model served as the operational framework to ensure systematic product development, validation, and implementation.

In the Analysis stage, learning needs were analyzed through classroom observations, interviews with teachers, and curriculum document reviews to identify student characteristics, material suitability, and learning problems related to 4C skills.

The Design stage included designing the structure of the e-module based on the integration of STEM and Project-Based Learning with the local context of Jambi, including formulating learning objectives, mapping materials, project scenarios, student activities, and designing instruments for assessing 4C skills.

The Development stage was carried out by developing digital e-modules according

to the designed specifications, followed by validation by subject matter experts, media experts, and learning experts using validation sheets to assess the suitability of the content, construction, and media display.

The Implementation stage was carried out by testing the e-module on students to obtain data on its practicality and user responses, while the Evaluation stage aimed to assess the effectiveness of the e-module in improving students' 4C skills and revising the product based on the evaluation results.

The research subjects consisted of junior high school students, namely grade VII MTsN 3 BatangHari, who were selected purposively according to the research needs, and one teacher as a user of e-modules in the learning process. Data collection instruments included: (1) observation sheets to observe the implementation of learning and student activities, (2) interview guidelines to explore the initial needs and feedback of teachers, (3) expert validation sheets to assess the validity of e-modules, (4) a practicality questionnaire to measure the ease of use and acceptability of the e-module, and (5) a 4C skills instrument in the form of tests and assessment rubrics. 4C skills are assessed through instruments such as: (a) Critical thinking skills were measured through contextual problem-based essay questions; (b) creativity was measured through product and project idea assessment rubrics; (c) collaboration was assessed using group work observation sheets; and (d) communication was measured through presentation and project report rubrics.

The validity of the 4C skills instruments was ensured through expert judgment involving two mathematics education experts and one learning media expert. The critical thinking test items were validated in terms of content relevance, clarity, and alignment with the indicators of 4C skills. Creativity and collaboration skills were assessed using performance-based rubrics adapted from commonly used 4C assessment frameworks in previous studies. The creativity rubric focused on indicators such as originality, flexibility of ideas, and elaboration in problem-solving, while the collaboration rubric assessed students' participation, role-sharing, responsibility, and interaction during group activities. All instruments were revised based on expert feedback before implementation.

Data analysis techniques included quantitative and qualitative descriptive analysis. Validity and practicality data were analyzed using percentages and feasibility categories, while improvements in students' 4C skills were analyzed using average scores and N-gain to determine the effectiveness of the e-module (Sari & Fauzi, 2025). Qualitative data from observations and interviews were analyzed descriptively to reinforce the interpretation of quantitative results and as a basis for product refinement. The N-Gain was calculated using the formula:

$$N - Gain = \frac{posttest\ score - pretest\ score}{maximum\ score - pretest\ score}$$

Furthermore, Hake (1999) states that normalized gain (N-Gain) assessment is classified into three levels, namely high for N-Gain values of 0.7 or above, medium for values ranging from 0.3 to less than 0.7, and

low for values of 0.3 or below. A product is regarded as acceptable when it attains an N-Gain score between 0.3 and 1.0. To ensure the validity and reliability of the findings, the researchers applied triangulation of sources and methods. Instrument reliability was examined through internal consistency analysis during the limited field trial. The results indicated that the 4C skills instruments were reliable and suitable for assessing students' performance in the learning context. Triangulation was carried out by comparing observation results, interview data, and quantitative findings from pretest and posttest. By using multiple sources and data collection techniques, the researchers ensured that the conclusions accurately reflected the real classroom conditions. This step was crucial for producing trustworthy results and enhancing the credibility of the study.

III. Result and Discussion

Study This produce product learning in the form of STEM-PBL Based E-Module with The Jambi context aims For Increase Students' 4C Skills. Product the developed through the five stages of the ADDIE model: Analysis, Design, Development, Implementation, and Evaluation. The effectiveness of the E-Module was evaluated through validation expert , trial limited with 26 students class VII, analysis results learning , and teacher interviews .

E-Module on research This will made use Canva and Flip HTML 5, The approach used in the E-Module, namely STEM and PBL based that combines learning indicators STEM- based and Steps in PBL which Steps learning the support the following 4C capabilities is results development of STEM-

PBL based E-Modules with context Jambi. here is the E-Module link: https://drive.google.com/file/d/1YjBTo46G R_KQ9KzgyJBjZ8eNm8lpZ_gt/view?usp=sha ring

This page aims to help users understand how to use the E-Module to its fullest potential. The introduction page contains a brief overview of the E-Module and a brief explanation of STEM-PBL used in this E-Module, as well as critical thinking indicators. The module sections are presented in Figure 3-8.

Figure 3. The Jambi Context for Starting Learning.

Figure 3 presents the integration of Jambi local context at the beginning of learning, which introduces cultural elements such as Tugu Tapa Malenggang as a contextual trigger for problem identification. This contextualization aims to engage students and link mathematical concepts with their real-life experiences.
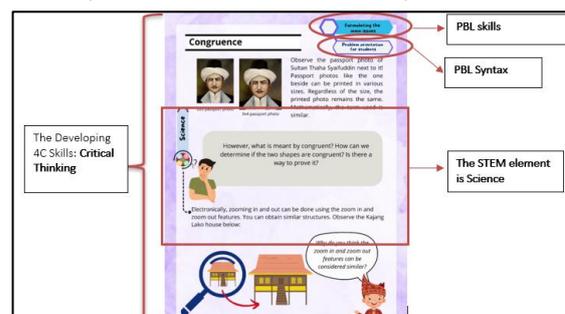

Figure 4. Material page of science element.

Figure 4 shows the problem formulation stage, which initiates students' critical thinking through contextual observation activities. This module page shows the problem formulation stage (PBL syntax) through observation of passport photos and traditional houses, which raises questions about the concept of congruence. This activity requires PBL skills such as identifying problems, gathering facts through observation, and beginning to develop initial reasoning. STEM elements are evident in the use of zoom in zoom out technology as a scientific context for understanding similarities in shape. In addition, this activity develops students' 4Cs, namely critical thinking when analyzing similarities between objects. Each material context is linked to the context of Jambi, one of which is the Jambi hero Sulthan Thaha Saifudin.
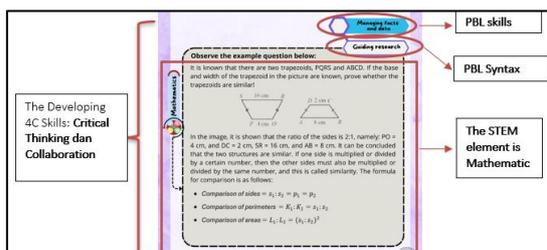

Figure 5. Material page Mathematic element.

Figure 5 demonstrates the guided inquiry phase, where students analyze mathematical relationships and patterns. This module page shows the stages of guided inquiry (PBL syntax) through activities that prove whether the trapezoids presented are congruent or not. This activity requires PBL skills such as identifying and managing facts and data, making logical arguments, and thinking critically. The STEM elements evident in this activity are Mathematics, where students are required

to prove congruence using mathematical concepts and theories as well as generalizations based on mathematical patterns. In addition, this activity develops students' 4Cs: Critical Thinking, because students are required to analyze data, compare ratios, and examine the conditions for congruence; and Collaboration, when conducting joint investigations.
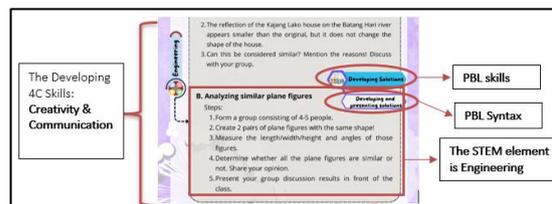

Figure 6. Material page of Engineering element.

Figure 6 depicts the engineering stage, focusing on designing and testing solutions. This module page shows the stages of developing and presenting solutions (PBL syntax) through discussion activities. Analyzing similar flat shapes by doing practical activities requires PBL skills such as making logical arguments, developing solutions, and scientific communication. The STEM elements evident in this activity are Engineering through designing and compiling alternative solutions to problems by conducting hands-on activities to prove whether the flat shapes are similar. In addition, this activity develops students' 4Cs, namely Creativity by creating models or diagrams to prove similarity and Communication by presenting solutions logically.

Figure 7. Material page of Technology element.

Figure 7 presents the use of technology through QR-code-based quizzes. This module page shows the stage of Organizing Students for Learning (PBL syntax) through a quiz activity where students are asked to form groups to work on the quiz provided in the QR code. This activity requires PBL skills such as managing facts to solve the problems given in the quiz. The STEM elements evident in this activity are the use of technology with the help of QR codes to display questions, and then each student is asked to scan the QR code. In addition, this activity develops the 4Cs in students, namely Collaboration through group discussions to determine problem-solving strategies and Communication, which is conveying an understanding of the initial facts.
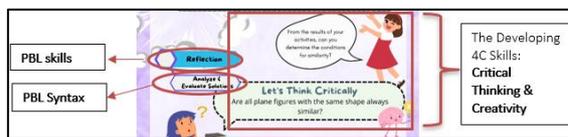

Figure 8. Material page of Critical Thinking & Creativity.

Figure 8 highlights the evaluation stage, which emphasizes reflection, critical analysis, and creative problem-solving. This module page shows the Analyzing & Evaluating Solutions stage (PBL syntax) through activities that review the concepts that have been discovered and answer questions that trigger critical thinking, thus requiring students to reflect on the lessons they have learned. This activity develops 4C skills, particularly Critical Thinking through the evaluation of errors and assessment of the effectiveness of solutions, as well as Creativity through the improvement process. The material page presents a description of Similarity integrated with the STEM approach and the PBL model. The

student activity page contains group activities to aid conceptual understanding. The exercise page contains questions at the end of each subchapter as a final evaluation, while the discussion page provides additional independent or group activities to deepen students' understanding with the teacher acting as a facilitator.

These integrated learning stages ensure that all components of 4C skills—critical thinking, creativity, communication, and collaboration—are systematically facilitated during the learning process

At the development stage, the research instruments were validated and the E-Module was tested for validity and practicality. The results of instrument validation are presented in Table 1.

Table 1.
Instrument Validation Questionnaire

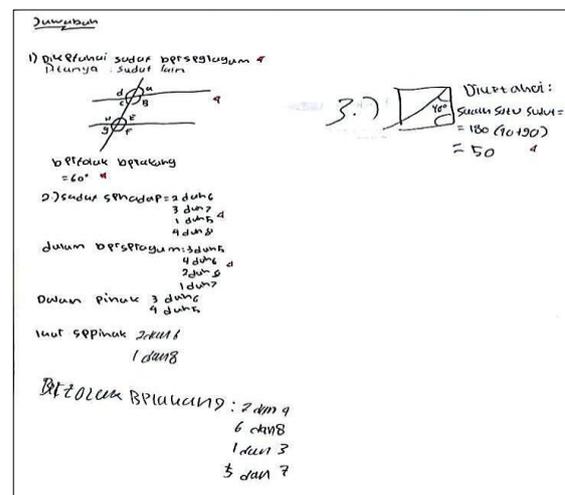| No	Research Instruments	Percentage	Category
1	Material Validation Questionnaire	95%	Very valid
2	Design Validation Questionnaire	93%	Very valid
3	Practicality Questionnaire by Teachers	93%	Very valid
4	Practicality Questionnaire by Students	93%	Very valid
5	Student Response Questionnaire	95%	Very valid
6	Critical Thinking Skills Test for Students	91%	Very valid

Table 1 indicates that all instruments achieved high validity levels, with percentages ranging from 91% to 95%, categorized as "very valid." Specifically, the material validation obtained a score of 95%, and design validation reached 93%, indicating that the e-module meets academic and pedagogical standards.

Furthermore, the practicality evaluation showed that the e-module was rated as "very practical" by both teachers (93%) and students (93%). These results indicate that the developed e-module is easy to use, accessible, and supportive of effective classroom learning.

After obtaining instrument validation, material validation was carried out by material experts, which obtained a percentage of 95% and was included in the "Highly Valid" category. Design validation by design experts obtained a percentage of 93% and was included in the "Highly Valid" category. The practicality criteria of the STEM-PBL-based E-Module using the cultural context of Jambi to improve the 4C abilities of junior high school students in the subject of similarity were assessed using a practicality questionnaire for teachers and a practicality questionnaire for students. The practicality level assessed by teachers was 93% and was categorized as "Very Practical". The level of practicality of the E-Module by students was 93% and was categorized as "Very Practical". Next, a field trial was conducted in class VII.1 MTs N 3 Batang Hari with 26 students, which was carried out in 3 meetings and 1 meeting to conduct a post-test. At the end of the meeting, students were given a student response questionnaire.

At the Implementation stage, learning is carried out using STEM-PBL-based E-Modules, which can be used as independent teaching materials by students. Based on the E-Module effectiveness data, the E-Module effectiveness level obtained by students was 80% in the "Effective" category, and the students' 4C skills test N-Gain score was 0.70 or 70%. Based on this, it can be concluded that the STEM-PBL-

based E-Module using the Jambi cultural context in the topic of similarity can enhance students' 4C skills. Based on the students' answers, the 4C skills can be analyzed based on each competency that appears on the answer sheet. The results of the analysis of the students' answers are as follows:

Translation:
1. Given: opposite angle
Question: the other angle is?
opposite angles = 60°
2. congruent angles =
2 and 6
3 and 7
1 and 4
4 and 8
opposite angle =
3 and 5
4 and 6
2 and 8
1 and 7
Same-side interior angles =
3 and 6
4 and 5

Same-side exterior angles =
2 and 6
1 and 8
Vertical Angle =
2 and 4
6 and 8
1 and 3
5 and 7

3. Given:
one of the angles = 90
180 (40 + 90)
= 50

Figure 9. Results in solving problems.

Figure 9 show student work that integrates all four elements of the 4Cs, including: critical thinking is evident when students identify "knowns–unknowns," draw intersecting parallel lines, label angles 1–8, then reason about the relationships between angles (corresponding angles, opposite interior angles, opposite exterior angles, and opposite angles) and use the

sum of the triangle's angles, 180°, to obtain the unknown angle (e.g., 180–(90+40)=50), thus demonstrating a flow of reasoning from data to conclusion; Creativity is evident in the strategies of sketching, coding numbers, and listing angle pairs as independent ways to organize information and check the possibility of more than one relevant rule; Communication is evident in writing down sequential steps, using mathematical terms/symbols, and making explicit calculations so that others can follow the reasoning behind each decision; Collaboration is reflected in the neat numbering of angles and the list of pairs, which facilitates cross-checking, assignment of tasks (e.g., who checks opposite or adjacent angles), and group discussion to agree on the correct angle values.

The effectiveness of the STEM-PBL-based e-module was evaluated based on students' performance in the 4C skills test. The field trial involving 26 students resulted in an average post-test score of 86.9%, with an N-gain value of 0.78, which falls into the high category. Figure 9 illustrates a representative example of students' problem-solving performance, demonstrating the integration of critical thinking, creativity, communication, and collaboration skills. The overall results indicate a consistent improvement across all four 4C components after the implementation of the e-module. These findings suggest that the developed e-module effectively enhances students' 4C skills in mathematics learning.

Analysis of the students' responses to the post-test items demonstrates a notable improvement across all four components of the 4C skills following the implementation of the STEAM-PBL based e-module incorporating Jambi cultural contexts. The STEAM-PBL based e-learning module that integrates the cultural context of Jambi shows a significant improvement in the four components of 4C skills, according to an analysis of student responses to post-test questions. Students showed improvement in critical thinking by better solving problems, finding important information, and choosing the right solution strategies. Students showed improvement in analytical and evaluative skills, providing stronger reasoning and demonstrating greater accuracy in formulating conclusions compared to the pre-test.

Similarly, students showed clear progress in creative thinking, as reflected in their ability to propose novel ideas, explore alternative solution pathways, and produce varied representations of their answers. The learning intervention appears to have successfully stimulated their creative cognitive processes, as evidenced by the change from stiff, single-pattern replies in the pre-test to flexible and contextually adaptive solutions in the post-test.

In terms of communication abilities, the results show that students improved their ability to communicate their ideas during class discussions, explain procedural procedures, and articulate their thinking. Their explanations were more organized and understandable, suggesting that PBL's participatory format fostered increased confidence and clarity in the expression of mathematical ideas.

During group activities, the growth of cooperation skills was also evident. When completing problem-solving assignments, students showed improved coordination,

more equitable task distribution, and more involvement. Active listening, constructive criticism, and mutual support are examples of observable improvements in cooperation dynamics that show how the STEAM-PBL learning environment promoted more significant cooperative participation among students.

During the implementation stage, the evaluation conducted was to ensure that the researchers delivered appropriate learning materials so that there were no misunderstandings and to ensure that the learning process ran in accordance with the teaching modules and learning designs that the researchers had previously created. The results of observations of learning implementation while using the e-module obtained an average score of 88.6%. The researcher also observed the students' learning process and measured their understanding of the material through a post-test of their 4C skills. Quantitatively, the results of the research on the 4C skills shown in Table 2.

Table 2. Quantitative Results of 4C Skills

4C Components	Average Pre-Test Score	Average Post-Test Score	Percentage of Completion	N-Gain	N-Gain Category
Critical Thinking	45.3	85.6	85.6%	0.75	Moderate
Creative Thinking	49.6	81.2	81.2%	0.73	Moderate–High
Communication	54.1	91.5	91.5%	0.86	Moderate–High
Collaboration	55.7	89.3	89.3%	0.78	High
Total	51.175	86,9	86,9%	0.78	High

Table 2 presents quantitative results on students' improvement in 4C skills. Based on Table 2, the average pre-test score across all 4C components was 51.18, which increased to 86.90 in the post-test, indicating a substantial improvement after the implementation of the STEM-PBL-based e-module.

In the critical thinking component, the average score increased from 45.3 in the pre-test to 85.6 in the post-test, with an N-Gain value of 0.75, categorized as medium. The creative thinking skill also showed a notable improvement, with scores rising from 49.6 to 81.2 and an N-Gain of 0.73 (medium–high category).

For communication skills, students' average scores increased from 54.1 to 91.5, resulting in an N-Gain value of 0.86, which falls into the medium–high category.

Similarly, collaboration skills improved from an average pre-test score of 55.7 to a post-test score of 89.3, with an N-Gain of 0.78, categorized as high.

Overall, the total N-Gain value of 0.78 indicates a high level of improvement in students' 4C skills following the use of the developed e-module

Overall, the findings show that incorporating STEAM-PBL into an e-module format increased students' broader 21st-century competencies in addition to producing quantifiable improvements in their performance on assessment tasks. These results confirm that contextualized, inquiry-driven digital learning materials can help students strengthen their interpersonal and cognitive skills in the classroom.

The evaluation stage in this study was carried out at each stage of development in accordance with the ADDIE model to ensure that the product, namely the STEM-PBL-based E-Module Using the Cultural Context of Jambi, met the criteria of being valid, practical, and effective in improving the 4C abilities of junior high school students. At the analysis stage, the evaluation was carried out after interviews that showed learning gaps and a lack of focus among students. Based on these findings, the researcher designed more innovative and efficient learning media to help students understand the material, namely the STEM-PBL-based E-Module with the cultural context of Jambi.

During the development stage, researchers began compiling the E-Module according to the design that had been developed in the previous stage, then conducted validation by a team of experts to obtain comments and suggestions related to the STEM-PBL-Based E-Module Using the Cultural Context of Jambi in the subject of Similarity. Input from experts became the basis for improvements to make the module more suitable for use. After validation, researchers continued with practical testing through individual and small group trials. The input from this stage was also used to evaluate and refine the E-Module so that the final product was truly ready and suitable for use in research.

During the implementation stage, the evaluation conducted by the researchers ensured that the learning material was delivered appropriately, so that there were no misunderstandings and that the learning process ran in accordance with the teaching module and learning design that the

researchers had previously created. The results of observations of the learning process while using the e-module obtained an average score of 88.6%. The researchers also observed the students' learning process and measured their understanding of the material through a post-test of their 4C skills. Quantitatively, the results of the research on the 4C skills are as follows:

The findings of this study demonstrate that the STEM-PBL-based e-module integrated with the cultural context of Jambi effectively enhanced students' 4C skills. Rather than merely presenting quantitative improvements, these results can be understood through the theoretical lens of constructivist learning, problem-based learning, and culturally relevant pedagogy.

The relatively high N-Gain value (0.78) obtained in this study indicates a substantial improvement in students' 4C skills. When compared with previous studies on STEM-PBL-based learning materials, this result is comparable to or slightly higher than reported gains. For instance, Purnamasari et al. (2020) and Kurniati et al. (2021) reported medium to high N-Gain values (0.60–0.75) in STEM-PBL-based e-modules focusing primarily on critical thinking skills. Similarly, Rohmatulloh et al. (2023) found an N-Gain of approximately 0.72 in problem-based e-modules for junior high school mathematics. The higher N-Gain achieved in the present study suggests that the integration of STEM-PBL with local cultural contexts may provide added value by increasing student engagement and contextual relevance, thereby supporting deeper learning.

From a theoretical perspective, the improvement in critical thinking skills can be

explained by the problem-oriented structure of STEM-PBL, which requires students to identify problems, analyze information, and evaluate solutions systematically (Hacioglu & Gulhan, 2021). Classroom observations showed that students were more actively involved in identifying known and unknown information, drawing representations, and justifying their reasoning during problem-solving activities. This finding aligns with constructivist theory, which emphasizes knowledge construction through active cognitive engagement and social interaction.

The development of creativity was supported by open-ended project tasks embedded in the e-module. Students were encouraged to explore multiple solution strategies and produce varied representations, such as sketches, models, and alternative reasoning pathways. Observational data indicated that students who initially relied on single-solution approaches began to demonstrate flexibility and originality in their responses. This supports previous findings that STEM-integrated learning environments can foster creative thinking by allowing students to experiment and iterate solutions (Jonsson et al., 2020; Gustiningsi et al., 2024, 2025; Thornhill-Miller et al., 2025).

Improvements in communication and collaboration skills were closely related to the collaborative nature of PBL activities. Group discussions, presentations, and shared problem-solving tasks required students to articulate their ideas and negotiate solutions with peers. Observations revealed increased student participation, clearer verbal explanations, and more balanced role distribution within groups compared to the pre-research stage. These findings are consistent with Vygotsky's social development theory, which emphasizes the role of social interaction and language in cognitive development (Remorosa et al., 2024), as well as studies indicating that PBL environments enhance collaborative competencies.

The integration of Jambi's cultural context played a critical role in strengthening students' engagement and meaningful learning. By situating mathematical concepts within familiar cultural elements, such as local monuments and environmental contexts, students were able to relate abstract concepts to real-life experiences. This finding supports culturally relevant pedagogy, which posits that learning becomes more effective when students' cultural backgrounds are acknowledged and incorporated into instructional materials (Izzania et al., 2024). In the context of mathematics education, such integration not only enhances cognitive outcomes but also promotes positive learning attitudes and cultural awareness (Pasaribu, Gustiningsi, & Nusantara, 2025).

From an educational perspective, these findings imply that STEM-PBL-based e-modules with local cultural integration can serve as an effective instructional strategy to support the development of 21st-century skills in junior high school mathematics. Teachers can utilize such digital learning materials to move beyond procedural teaching and foster higher-order thinking,

creativity, communication, and collaboration. Moreover, this approach aligns with current curriculum demands that emphasize contextual, student-centered, and technology-enhanced learning.

IV. CONCLUSION

The results of the study show that the STEM-PBL based E-Module developed through the ADDIE model has a very high level of feasibility. The validity of the module reached an average of 93%, with a score of 92% in terms of material and 94% in terms of design, indicating that the content and structure meet academic and pedagogical standards. In terms of practicality, individual trials scored 92% and small group trials scored 89%, resulting in an average practicality score of 90.5% and indicating that the module is easy to use and supports effective learning flow. Observations of the learning process also resulted in a score of 88.6%, indicating that the implementation of the module went very well in accordance with the STEM-PBL syntax. The effectiveness of the module can be seen from the 4C skill score gain of 0.78 (high category) and the positive response of 80% of students. Overall, this E-Module has been proven to be valid, practical, and effective, as well as an innovative solution for developing 4C skills through the integration of context-based STEM-PBL in the Indonesian educational environment.

The findings of this study indicate that the integration of STEM-PBL learning in electronic modules has great potential to improve students' higher-order thinking skills, especially in junior high school geometry. The combination of contextual problem solving, cross-disciplinary

activities, and student-centered learning strategies has been proven to strengthen critical thinking, creativity, communication, and collaboration skills. However, this study has limitations in terms of the small number of subjects and its focus on a single topic and grade level. To broaden the generalization, further research is recommended to apply the STEM-PBL E-Module to other mathematics materials with a more diverse sample. Longitudinal studies are also needed to examine the long-term impact of the module on cognitive development and learning independence. Overall, this study makes an important contribution to educators and media developers in designing innovative digital learning resources that meet the demands of the 21st century.

ACKNOWLEDGEMENT

REFERENCES

Ajayan, P., Cao, R., & Eichler, J. F. (2025). Promoting Conceptual Learning Using Scaffolded Activities That Incorporate Interactive Simulations. *Education Sciences*. https://doi.org/https://doi.org/10.3390/educsci15050566

Cynthia, Arafah, K., & Palloan, P. (2023). Development of Interactive Physics E-Module to Improve Critical Thinking Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(5), 3943–3952.

https://doi.org/10.29303/jppipa.v9i5.2302

Endang Indarini. (2024). Dampak Model Problem Based Learning Terhadap Keterampilan Abad 21 (4 C) di Sekolah Dasar. *Satya Widya*, *40*(1), 73–87. https://doi.org/10.24246/j.sw.2024.v40.i1.p73-87

Fausih, M., & Danang, T. (2015). Pengembangan Media E-Modul Mata Pelajaran Produktif Pokok Bahasan "Instalasi Jaringan Lan (Local Area Network)" Untuk Siswa Kelas Xi Jurusan Teknik Komputer Jaringan Di Smk Nengeri 1 Labang Bangkalan Madura. *Jurnal UNESA*, *01*(01), 1–9.

Frisky Rapika Dwi, Feri Tiona Pasaribu, & Yelli Ramalisa. (2024). Pengembangan Modul Elektronik Berbasis PjBL-STEM dengan Bantuan Film Animasi untuk Meningkatkan Minat Belajar Matematika Siswa SMA. *Jurnal Pendidikan Mipa*, *14*(1), 67–78. https://doi.org/10.37630/jpm.v14i1.1472

Gustiningsi, T., Pasaribu, F. T., & Ramalisa, Y. (2025). Analysis of the Mathematical Literacy Ability of Middle School Students in Jambi City in Solving PISA Questions. *AIP Conference Proceedings*, *3446*, 030015. https://doi.org/10.1063/5.0308689

Gustiningsi, T., Putri, R. I. I., Zulkardi, & Hapizah. (2024). LEPscO: Mathematical Literacy Learning Environment for the Guru Penggerak Program. *Journal on Mathematics Education*, *15*(2), 661–682. https://doi.org/https://doi.org/10.22342/jme.v15i2.pp661-682

Hacioglu, Y., & Gulhan, F. (2021). The Effects of STEM Education on the 7th Grade Students' Critical Thinking Skills and STEM Perceptions. *Journal of Education in Science, Environment and Health*.

https://doi.org/10.21891/jeseh.771331

Hairunnisa, F., Elvi, M., & Liana, M. (2023). Analisis Literasi Matematika Siswa SMP Dalam Menyelesaikan Soal Model AKM Pada Konten Geometri. *Buana Matematika: Jurnal Ilmiah Matematika Dan Pendidikan Matematika*, *13*(1), 23–36. https://doi.org/10.36456/buanamatematika.v13i1.7923

Hake, R. R. (1999). *Analyzing change/gain scores*. Indiana University. https://doi.org/IndianaUniversity

Handayani, T., Winarni, E. W., & Koto, I. (2021). Pengembangan Media Komik Digital Berbasis STEM dalam Meningkatkan Kemampuan Literasi Sains Siswa Sekolah Dasar Endang Widi Winarni Irwan Koto. *JP3D (Jurnal Pembelajaran Dan Pengajaran Pendidikan Dasar)*, *4*(1), 22–29.

Haviz, M. (2009). Berpikir Dalam Pendidikan: (Suatu Tinjauan Filsafat Tentang Pendidikan Untuk Berpikir Kritis). *Ta'dib*, *11*(2). https://doi.org/10.31958/jt.v12i1.158

Hysa, F., & Jakupi, R. (2023). Education Is a Key Tool in the Development of Society and Educational Leadership and Is a Key Element for Effective School and Education. *Education Is a Key Tool in the Development of Society and Educational Leadership and Is a Key Element for Effective School and Education*, *29*(4), 1509–1520. https://doi.org/10.53555/kuey.v30i4.1007

Isnania, Marzal, J., & Pasaribu, F. T. (2025). *Pengembangan E-Modul Berbasis Realistic Mathematics Education (Rme) Menggunakan 3d Pageflip Professional Pada Materi Teorema Pythagoras*. *9*.

Izzania, R. A., Sumarni, W., & Harjono, H. (2024). Pengembangan E-Modul Ajar Kimia Hijau Bermuatan Etno-STEM

Berbasis Guided Inquiry untuk Membekali Kemampuan Berpikir Kritis Peserta Didik. *Jurnal Inovasi Pendidikan Kimia*, *18*(1), 7–16. https://doi.org/10.15294/jipk.v18i1.46536

Jihan Nurhamidah, & Arladia Hafsya. (2024). Pengembangan Keterampilan 4C (Critical, Thinking, Creativity, Communication, and Collaboration) dalam Pembelajaran IPS untuk Menjawab Tantangan Abad 21. *Aliansi: Jurnal Hukum, Pendidikan Dan Sosial Humaniora*, *2*(1), 28–39. https://doi.org/10.62383/aliansi.v2i1.635

Jonsson, B., Granberg, C., & Lithner, J. (2020). Gaining Mathematical Understanding: The Effects of Creative Mathematical Reasoning and Cognitive Proficiency. *Frontiers in Psychology*, *11*, 574366. https://doi.org/10.3389/fpsyg.2020.574366

Kamid, & Ramalisa, Y. (2019). Pengembangan Modul Pembelajaran Matematika SMP Berbasis Budaya Jambi Untuk Siswa Autis. *Edumatica : Jurnal Pendidikan Matematika*, *9*(1), 75–84. https://doi.org/10.22437/edumatica.v9i1.6515

Khoirunnissa, R., Suwarma, I. R., & Muslim, M. (2024). The Implementation of STEM-PBL Learning to Enhance Students' Critical Thinking Skills. *Jurnal Pendidikan Fisika Dan Teknologi*, *10*(1), 175–185. https://doi.org/10.29303/jpft.v10i1.6879

Kurniati, R. D., Andra, D., & Distrik, I. W. (2021). E-module development based on PBL integrated STEM assisted by social media to improve critical thinking skill: A preliminary study. *Journal of Physics: Conference Series*, *1796*(1). https://doi.org/10.1088/1742-6596/1796/1/012077

Lestari, R. V. A., & Hindun. (2023). Penerapan 4C (Communication, Collaboration, Critical Thinking, Creativity) Pada Kurikulum Merdeka Di Tingkat SMA. *Journal of Indonesian Language Research*, *3*(2), 15–26.

Madu, A., Nenotaek, B., & Agil, A. F. (2025). Development of ethnomathematics-based e-modules to improve student learning outcomes on circle material. *International Journal of Innovative Research and Scientific Studies*, *8*(4), 1347–1362. https://doi.org/10.53894/ijirss.v8i4.8069

Margaretha, L., Pasaribu, F. T., & Ramalisa, Y. (2024). Pengembangan E-LKPD Berbasis STEM Berbantuan Video Animasi untuk Meningkatkan Kemampuan Berpikir Kritis Siswa SMA. *Jurnal Pendidikan MIPA*, *14*(1), 90–98.

Nabilah, B. S., Pasaribu, F. T., & Gustiningsi, T. (2025). Pengembangan E-Modul Berbasis STEM Berbantuan Augmented Reality pada Materi Kubus. *Al-Irsyad: Journal of Education Science*, *5*(1 SE-Artikel), 85–98. https://doi.org/10.58917/aijes.v5i1.558

Nia, N., Leksono, S. M., & Nestiadi, A. (2022). Pengembangan E-Modul Pelestarian Lingkungan Berbasis Problem Based Learning (PBL) Untuk Meningkatkan Kemampuan Berpikir Kritis Siswa SMP. *PENDIPA Journal of Science Education*, *6*(2), 415–421. https://doi.org/10.33369/pendipa.6.2.415-421

Nurhayati, I., Pramono, K. S. E., & Farida, A. (2024). Keterampilan 4C (Critical Thinking, Creativity, Communication and Collaboration) dalam Pembelajaran IPS untuk Menjawab Tantangan Abad 21. *Jurnal Basicedu*, *8*(1), 36–43.

https://doi.org/10.31004/basicedu.v8i1.6842

Nurlaela, E., & Imami, A. I. (2022). Peningkatan Kemampuan Literasi Matematika Siswa Melalui Penerapan Model Pembelajaran Problem Based Learning Di Kelas VII SMPIT Insan Harapan. *Jurnal Ilmiah Dikdaya*, *12*(1), 33. https://doi.org/10.33087/dikdaya.v12i1.270

Pasaribu, F. T., Gustiningsi, T., Ariefah, H., Matematika, P. P., & Jambi, U. (2025). Effectiveness of STEM-PBL Based E-Modules on Critical Thinking Skills of Junior High School Students. *Logaritma*, *13*(01), 49–60.

Pasaribu, F. T., Gustiningsi, T., & Nusantara, D. S. (2025). *Design of a Project-Based Learning Module in the Jambi Context Based on 3-Full Deep Learning to Enhance 6C Skills Introduction*.

Pujiono, Sutiarso, S., & Dahlan, S. (2024). Pengembangan Pembelajaran Menggunakan E-Modul Problem Based Learning Untuk Meningkatkan Kemampuan Berpikir Kritis Peserta Didik. *Jurnal Program Studi Pendidikan Matematika*, *13*(2), 567–576.

Purnamasari, D., Ashadi, & Utomo, S. B. (2020). Analysis of STEM-PBL based e-module needs to improve students' critical-thinking skills. *Journal of Physics: Conference Series*, *1511*(1). https://doi.org/10.1088/1742-6596/1511/1/012096

Remorosa, M. M. R., Capili, S. R., Decir, E. G. B., & Julius, B. (2024). *Vygotsky's Social Development Theory : The Role Of Social Interaction And Language In Cognitive Development*. *6*(December), 10–13.

Robert Maribe, B. (2009). Approach, Instructional Design: The ADDIE. In *Department of Educational Psychology and Instructional Technology University of Georgia* (Vol. 53, Number 9).

Rohmatulloh, R., Nindiasari, H., & Fatah, A. (2023). Pengembangan E-Modul Interaktif Berbasis Problem Based Learning (Pbl) Untuk Meningkatkan Kemampuan Berpikir Kritis Matematis. *AKSIOMA: Jurnal Program Studi Pendidikan Matematika*, *12*(4), 3599. https://doi.org/10.24127/ajpm.v12i4.8172

Rosyidi, M. I. (2018). *Peranan Logika Matematika Dalam Kehidupan Sehari-hari*. *1*, 28–32.

Saparuddin. (2022). Penggunaan E-Modul Sebagai Solusi Untuk Meningkatkan Motivasi dan Kemandirian Belajar Peserta Didik. *Prosiding Seminar Nasional Biologi FMIPA UNM*, 445–452.

Saputri, S. E., Ramalisa, Y., Pasaribu, F. T., & Gurstiningsi, T. (2025). Pengembangan E-Modul Berbasis Problem Based Learning untuk Meningkatkan Kemampuan Literasi Matematis Siswa. *Kognitif: Jurnal Riset HOTS Pendidikan Matematika*, *5*(2 SE-Articles), 947–960. https://doi.org/10.51574/kognitif.v5i2.3351

Sari, D. N., & Fauzi, K. M. A. (2025). Development and Validation of Realistic Mathematics Education-Based Worksheets for Junior High School Students. *Mathematics Teaching Research Journal*, *17*(1), 99–127.

Susanty, L., Rahmat, T., Aniswita, A., & Fitri, H. (2023). Pemahaman Konsep Matematika Siswa Dengan Model Pembelajaran Conceptual Understanding Procedures (CUPs). *EDUSAINS: Journal of Education and Science*, *1*(1 SE-Articles), 1–8. https://doi.org/10.57255/edusains.v1i1.246

Syaharani, D. N., Feri Tiona Pasaribu, Tria Gustiningsi, & Nusantara, D. S. (2022). Pengembangan E-Modul Berbasis Problem Based Learning- Augmented Reality Bermuatan Soal PISA untuk Meningkatkan Kemampuan Penalaran Matematis Siswa. *Jurnal Pendidikan MIPA*, *12*(1), 1–7.

Thornhill-miller, B., Camarda, A., Mercier, M., Burkhardt, J., Morisseau, T., Bourgeois-bougrine, S., Vinchon, F., Hayek, S. El, Augereau-landais, M., Mourey, F., Feybesse, C., Sundquist, D., & Lubart, T. (2025). *Creativity, Critical Thinking, Communication, and Collaboration: Assessment, Certification, and Promotion of 21st Century Skills for the Future of Work and Education*.

Walipah, Firdaus, R. M., & Chasanah, F. (2024). Effectiveness of Problem-Based Learning and Discovery Learning Models on Learning Outcomes of Social Science Students. *Tarbiyah: Jurnal Ilmiah Kependidikan*, *13*(1), 81–89.

Wulandari, D. U., Mariana, N., Wiryanto, W., & Amien, M. S. (2024). Integration of Ethnomathematics Teaching Materials in Mathematics Learning in Elementary School. *IJORER: International Journal of Recent Educational Research*, *5*(1), 204–218. https://doi.org/10.46245/ijorer.v5i1.542

AUTHOR'S BIOGRAPHY
Feri Tiona Pasaribu, S.Pd., M.Pd.

Born in Medan on February 3, 1986. She is a lecturer in the Mathematics Education Department of Universitas Jambi. She completed her undergraduate studies in Mathematics Education at Universitas Negeri Medan in 2010, then her master's studies in Mathematics Education at Universitas Negeri Medan in 2012. Her research interests include STEM and digital media learning, and Design Research.

Dr. Tria Gustiningsi, M.Pd.

Born in Palembang on August 15, 1990. She is a lecturer in the Mathematics Education Department of Universitas Jambi. She completed her undergraduate studies in Mathematics Education at Universitas Sriwijaya in 2012, then her master's studies in Mathematics Education at Universitas Sriwijaya in 2015, and her doctoral studies in Mathematics Education at Universitas Sriwijaya in 2023. Her research interests include mathematical literacy, PISA, Higher Order Thinking Skills (HOTS), and Design Research.

Isnania, S.Pd., M.Pd.

Born in Jambi on December 22, 1997. She is a lecturer in the Elementary School Teacher Education Department of Universitas Jambi. She completed her undergraduate studies in Mathematics Education at Universitas Jambi in 2020, then her master's studies in Mathematics Education at Universitas Jambi in 2022. Her research interests include digital media learning.

Leizel P. Ariem Concepcion, Ph.D

Born in Nagbacalan, Paoay, Ilocos Norte, Philippines, on August 7, 1979. She is presently an Assistant Professor at the Mariano Marcos State University (MMSU), College of Teacher Education, where she teaches Science and Professional Education courses. She earned both her Bachelor's degree and Master's degree from MMSU, where she is currently employed. She completed her Doctor of Philosophy in Science Education at Don Mariano Marcos Memorial State University, College of Graduate Studies, South La Union Campus, Agoo, La Union. Her research interests focus on science literacy and educational research in the areas of curriculum and instruction, online and technology-enhanced teaching, and teacher education.