



Contextual-STEM-Based E-Module Development in Enhancing Junior High School Students' Mathematical Reasoning Abilities

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Abstract: The disconnect between mathematics content and real-world applications creates significant challenges for students' understanding of fraction operations, resulting in procedural learning without conceptual depth. This study develops and evaluates a STEM-based e-module integrating authentic contexts with systematic instructional design to enhance junior high school students' mathematical reasoning abilities. The research employed the ADDIE development model to create a STEM-based e-module on fraction operations using snack nutritional values as context. The Engineering Design Process (EDP) served as the central pedagogical framework, structuring activities through seven systematic stages: Define, Research, Plan, Create, Communicate, Redesign, and Evaluate, transforming abstract mathematical concepts into meaningful problem-solving experiences. Three experts validated the e-module across five dimensions: content feasibility, presentation quality, language appropriateness, practicality, and STEM integration. Practicality testing involved progressive trials: one-to-one (3 students), small group (6 students), and field implementation (30 students). Mathematical reasoning effectiveness was measured using contextual problem-solving assessments evaluating five indicators: conjecturing, pattern identification, mathematical manipulation, justification provision, and conclusion drawing. Validation results demonstrated exceptional quality, with the e-module achieving a 95.2% overall validity index. Practicality testing revealed an average satisfaction of 90.28%, categorized as "very practical." Students demonstrated substantial improvement in mathematical reasoning, with an average final assessment score of 77.68. Students performed strongest in drawing conclusions (87%) and providing justification (81.67%), while conjecturing achieved a rate of 64%. Qualitative analysis revealed that while high-ability students employed formal reasoning and symbolic representation, some medium-ability students relied more on narrative responses, reflecting a gap between intuitive understanding and formal expression. The study concludes that the developed e-module is valid, practical, and effective in fostering students' mathematical reasoning. Integrating EDP into STEM-based e-modules provides a promising pathway to bridge procedural knowledge and conceptual depth, promoting meaningful and transferable learning experiences.

Keywords: contextual learning, engineering design, fractions context, mathematical reasoning, STEM e-module.

▪ INTRODUCTION

The rapid advancement of technology has transformed the global education landscape, shifting the focus from traditional content delivery to the cultivation of 21st-century skills such as critical thinking, problem-solving, and mathematical reasoning (Hähnlein et al., 2025; Tuong et al., 2023). Mathematics is central to this shift because it emphasizes abstract reasoning, logical argumentation, and its capacity to model real-world phenomena (Dominguez et al., 2023; Goos et al., 2023; Just & Siller, 2024). Consequently, strengthening students' mathematical reasoning abilities has become a key priority in modern curricula emphasizing interdisciplinary and conceptual learning (English, 2023; Guerra, 2024).

Mathematical reasoning encompasses constructing and justifying arguments, making logical connections, and applying mathematical ideas in real-life contexts. This multifaceted skill fosters conceptual understanding and supports students in solving complex, cross-disciplinary problems (Bertrand & Namukasa, 2023; English, 2023). In response to these demands, STEM education has emerged as a framework that supports reasoning development by integrating authentic, problem-based, and cross-disciplinary learning experiences (Goos et al., 2023; Just & Siller, 2024). When facilitated through digital technology, STEM learning becomes even more powerful, especially via interactive electronic modules that promote student engagement and reasoning through contextual and interdisciplinary content (Behnamnia et al., 2025; Boltsi et al., 2024; J. Huang et al., 2025).

However, recent studies have also identified limitations in STEM implementation, particularly in how mathematics is often marginalized or insufficiently integrated into problem-solving activities (English, 2023; Zhou et al., 2022). These concerns are especially prominent in contexts where instruction is dominated by procedural and non-contextual practices (Bertrand & Namukasa, 2023). This challenge is evident in Indonesia, where the mathematics curriculum emphasizes higher-order thinking skills (Atmojo et al., 2025). However, many students struggle with mathematical reasoning, particularly applying concepts to real-world problems. Field observations at a junior high school in Palembang revealed that approximately 70% of seventh-grade students struggled to perform fraction operations in contextual situations. Teachers noted students' reliance on rote memorization and their limited ability to justify or meaningfully apply their reasoning. These challenges are further compounded by instructional materials that are largely procedural, lack authentic contexts, and rarely support interdisciplinary integration (Antunes et al., 2023; Atmojo et al., 2025; Khalid et al., 2024; Rúa Martínez et al., 2024).

To address this issue, researchers have proposed the development of STEM-based electronic modules using structured instructional design models such as ADDIE (Analysis, Design, Development, Implementation, Evaluation). This model supports the systematic creation of pedagogically coherent, learner-centered digital resources aligned with clear instructional goals (Badaruddin et al., 2024; Bertrand & Namukasa, 2023; Wang & Chen, 2025). Studies have confirmed the potential of such modules in enhancing student achievement and reasoning development (Antunes et al., 2023; Barbosa et al., 2022; Behnamnia et al., 2025). Despite this, a lack of integrative research remains, combining STEM pedagogy, reasoning development, and the ADDIE model within a single, cohesive digital learning product, particularly in junior high school mathematics and fractions.

There is a growing demand for instructional media that are systematically designed, rooted in meaningful contexts, and responsive to classroom realities, particularly in mathematics education (English, 2023; Goos et al., 2023). Supporting this perspective, a systematic literature review by Ilma et al. (2023) analyzed 63 STEM-related studies in Indonesia between 2016 and 2021, revealing that most research addresses STEM pedagogy, digital innovation, or cognitive skill development separately. Only a small fraction of studies integrate these components into cohesive instructional designs, and even fewer focus on enhancing mathematical reasoning within contextualized topics such as fractions. This gap highlights the urgency of developing comprehensive interventions

that combine STEM principles, reasoning development, and structured instructional design frameworks.

This study aims to bridge that gap by developing and evaluating a STEM-based e-module grounded in the ADDIE model to enhance mathematical reasoning in junior high school students, using real-world nutritional contexts as an authentic foundation. The intervention integrates mathematics into interdisciplinary content and follows a structured design model, explicitly targeting reasoning enhancement in a conceptually challenging topic for many students: fraction operations. Accordingly, this study addresses the research question: How can a STEM-based e-module be systematically developed using the ADDIE instructional design model to enhance junior high school students' mathematical reasoning abilities in fraction operations? Additionally, the study assesses the validity, practicality, and effectiveness of the developed module in facilitating reasoning development through contextualized learning activities.

Unlike previous studies that tend to focus on isolated aspects of STEM integration, such as content delivery (Just & Siller, 2024), reasoning skills (English, 2023), or instructional design (Bertrand & Namukasa, 2023), this study offers a comprehensive intervention that merges all three. While prior research has contributed to understanding each element individually, few studies have systematically integrated mathematical reasoning into a STEM-based module structured using an established instructional design model, such as ADDIE. Moreover, very few have contextualized this integration within conceptually challenging topics such as fractions, especially in developing country contexts. This study positions itself to fill that void by offering a validated, practically aligned solution for enhancing students' reasoning through a fully integrated approach.

This research contributes to mathematics education by offering an innovative framework that unites STEM pedagogy, reasoning-focused instruction, and design-based development into a single digital learning product. Unlike prior studies, this research presents a replicable model that integrates these components fully and is grounded in authentic learning contexts. Its novelty lies in the methodological integration and practical alignment with classroom realities. It offers a scalable and empirically grounded solution to persistent reasoning difficulties frequently encountered in lower secondary mathematics education.

▪ **METHOD**

Participants

This study was conducted at a public junior high school in Palembang during the 2024/2025 academic year. The participants included seventh-grade students involved in three stages of formative testing: individual testing with three students, small-group testing with six students, and field testing with 30 students. The school was selected purposively based on accessibility, digital infrastructure readiness, and support from school administrators (Creswell & Clark, 2017; Yuliardi et al., 2024). Student selection used purposive sampling, considering prior mathematical achievement levels (low, medium, and high) to ensure diversity in learning profiles. This is crucial for comprehensively evaluating STEM-based mathematical interventions (Patton, 2015; Wan et al., 2023).

One mathematics teacher was also involved during the analysis phase. The teacher has over ten years of teaching experience, a bachelor's degree in mathematics education,

and is professionally certified under the Indonesian national teacher qualification framework (Beswick & Fraser, 2019; Sevimli & Ünal, 2022). Demographic data, including age, gender, and teaching experience, were recorded to inform the instructional design process, as teacher characteristics have been shown to significantly influence the effectiveness of STEM implementation (Just & Siller, 2024; Morrison et al., 2001). Ethical clearance was obtained before collection, and all participants provided informed consent after being briefed on the research procedures & objectives (Sullivan et al., 2021).

Research Design and Procedures

This study adopted a Research and Development (R&D) design to produce a STEM-based mathematics e-module that is valid, practical, and effective in enhancing students' mathematical reasoning abilities (English & Lehmann, 2024; Gall et al., 2002). The development process followed the ADDIE model, which includes five sequential stages: Analysis, Design, Development, Implementation, and Evaluation. This model provides a structured approach that supports iterative refinement and ensures pedagogical coherence in STEM education contexts (Branch, 2009; Goos et al., 2023).

The Analysis stage involved a comprehensive needs assessment through curriculum document reviews, mathematics teacher interviews, and student questionnaires (Y. Huang, 2024; Shakeel et al., 2022). These activities identified key learning challenges, explored students' digital habits, and assessed learning preferences to establish a foundation for designing a contextually appropriate and student-centered learning module that addresses contemporary mathematical thinking in STEM contexts (Adeoye et al., 2024; Hähnlein et al., 2025).

During the Design stage, the development team created a concept map, defined the instructional sequence, and prepared a storyboard incorporating real-world nutritional contexts following STEM integration principles (Dick et al., 2015; Dominguez et al., 2023). Research instruments, including expert validation forms, practicality questionnaires, and mathematical reasoning tests, were developed to align with instructional goals and capture the multidisciplinary nature of STEM learning (Amalina & Vidákovich, 2022).

The Development stage focused on creating the digital module using multiple technology tools: Canva for visual design, Wordwall for interactive game-based components, and Heyzine for 3D interactive e-book formatting (Clark & Mayer, 2016; Howorth et al., 2024). This approach emphasizes visual reasoning and interactive engagement consistent with contemporary digital STEM education practices (Miller, 2019; Thuneberg et al., 2018). Expert validation was conducted using Aiken's V to assess module clarity, coherence, and content integrity, with iterative revisions made based on feedback (Jawad et al., 2021; Shakeel et al., 2022).

The Implementation stage employed a tiered testing approach: one-to-one testing with three students of varying abilities to assess individual usability and comprehension, small-group testing with six students to identify interface and navigational issues, and field testing with thirty-seven grade students across four 90-minute instructional sessions in an authentic classroom setting. Each session began with a teacher-led orientation, followed by independent exploration using the Classkick platform, enabling real-time feedback and support (Shin et al., 2023). This progressive implementation supported mathematical reasoning development within a technology-integrated STEM learning environment (Ibrahim et al., 2024; Kong & Mohd Matore, 2021).

The field test also served as the basis for measuring the module's effectiveness, using a pre-experimental one-shot case study design. In this design, students received the learning treatment without a pretest or control group and were assessed only through a post-test on mathematical reasoning. This design is appropriate for early-phase evaluations of instructional innovations in real classroom settings, offering preliminary insight into learning outcomes and feasibility (Creswell & Clark, 2017; Fraenkel et al., 2012). The structured, progressive implementation aligns with standard formative evaluation practices in instructional design (Plomp, 2013; Tessmer, 1993), ensuring iterative refinement before summative testing.

Rather than a standalone final stage, evaluation was integrated throughout the ADDIE process to ensure continuous quality improvement. The field test utilized a pre-experimental one-shot case study design, measuring module effectiveness through a post-test assessment of mathematical reasoning without a pre-test or control group. This design is appropriate for early-phase evaluations of instructional innovations in real classroom settings (Creswell & Clark, 2017; Fraenkel et al., 2012). This distributed evaluation approach, incorporating triangulated needs assessment, expert validation, and field testing, ensured that each development phase was guided by evidence-informed reflection, enhancing the final product's validity, usability, and instructional quality (Plomp, 2013; Tessmer, 1993). Table 1 outlines the specific activities, outputs, and participants involved in each phase of the ADDIE model applied in this study

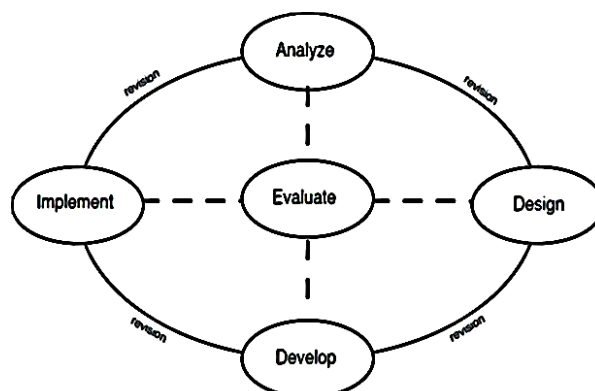


Figure 1. The ADDIE model for instructional development

Table 1. Activities and outputs in each phase of the ADDIE model

ADDIE Phase	Key Activities	Outputs	Participants
Analyze	Curriculum analysis, student diagnostic tests, and teacher interviews to identify learning needs and reasoning gaps in fraction operations	Identified student difficulties, contextual and pedagogical needs	Researchers, mathematics teachers
Design	Define learning objectives, select reasoning indicators, develop e-module structure, and contextual STEM tasks related to nutrition.	Module framework, storyboard drafts, assessment indicators	Researchers
Develop	Create digital content, integrate the Engineering Design Process (EDP) into tasks, develop an e-module using the	Validated e-module prototype, expert feedback reports.	Researchers, three expert validators.

ADDIE Phase	Key Activities	Outputs	Participants
	<i>Classkick</i> platform, conduct expert validation and formative evaluation through internal review and revisions.		
Implement	Conduct one-to-one trial (3 students), small group trial (6 students), and field test using one-shot case study design (30 students), collect usability and learning data, and formative evaluation for iterative revisions.	Field implementation data, usability and engagement feedback, and revised module version	Researchers, students, and classroom teachers.
Evaluate	Conduct summative evaluation through reasoning test results, student interviews, and practicality questionnaires; analyze learning impact.	Evidence of effectiveness, practicality metrics, and qualitative reasoning insights.	Researchers, a teacher, and 30 students.

Instruments

This study utilized four complementary instruments to support the development, validation, and evaluation of the STEM-based e-module. These instruments were designed to capture the complexity of mathematical reasoning in integrated STEM contexts and served distinct purposes across different research phases (Forde et al., 2023; Wan et al., 2023).

The first instrument was an expert validation rubric constructed to evaluate the e-module's quality in terms of content accuracy, pedagogical alignment, and integration of STEM principles (Queiruga-Dios et al., 2025). This rubric was validated by a panel of three experts with relevant backgrounds: a mathematics education lecturer (Ph.D.), a curriculum and instructional design specialist (M.Ed.), and a practitioner in STEM education (S.Pd., M.Sc.). Inter-rater consistency among the reviewers was measured using Aiken's V formula, and revisions to the module were made accordingly based on their feedback (Amirzadeh et al., 2024; Haryono et al., 2022).

The second instrument was a mathematical reasoning test of five open-ended items designed to capture students' reasoning processes in STEM contexts (Tashtoush et al., 2024). Each item was aligned with specific indicators, including conjecturing, identifying patterns, conducting mathematical manipulations, providing justification, and drawing conclusions. These represent core competencies for STEM-based mathematical thinking (Chang et al., 2021). The items were adapted from existing validated frameworks emphasizing interdisciplinary problem-solving (Amalina & Vidákovich, 2022). Two external mathematics educators reviewed and pilot-tested the test with a small group of students to ensure clarity, appropriateness, and cognitive alignment with contemporary STEM education standards (Shongwe, 2024).

The third instrument was a practicality questionnaire administered to students after the module was implemented. Using a five-point Likert scale, this questionnaire assessed students' perceptions of the module's usability, clarity of instructions, ease of navigation, visual design, and overall engagement with the learning content (Boone & Boone, 2012; Tanujaya et al., 2022). The questionnaire items were designed to capture students' experiences with digital STEM learning environments, drawing from recent research on

technology-enhanced mathematical learning (Susanta et al., 2023; Ziatdinov & Valles, 2022). Two educational technology experts validated and refined the instrument based on their recommendations to ensure content validity and reliability.

The final instrument was a semi-structured interview protocol to gather qualitative insights from students and the participating teacher (Pramasdyahsari et al., 2023). The interviews focused on exploring their experiences during the learning process, perceptions of the module's effectiveness, and any challenges encountered during implementation. Two qualitative research experts reviewed the protocol to ensure the appropriateness of question sequencing and content coverage. These qualitative data provided contextual depth that supported and enriched the quantitative findings, particularly in evaluating the module's practicality and relevance in real classroom settings where STEM integration poses unique pedagogical challenges (Creswell & Clark, 2017; Hebebcı & Usta, 2022).

Table 2. Indicators from validation and reasoning test rubrics

Instrument	Aspect	Indicator Example
Expert Validation Rubric	Content Accuracy	Learning content is conceptually correct and consistent with the current curriculum.
	Pedagogical Appropriateness	Learning activities are coherent with the learning objectives and student levels.
	STEM Integration	Real-world context is evident, and all STEM disciplines are meaningfully integrated.
	Visual-Communicative Design	Layout, typography, and color scheme support comprehension and engagement.
Mathematical Reasoning Rubric	Conjecturing	Students formulate mathematical hypotheses based on observed patterns.
	Pattern Identification	Students identify and extend regularities in mathematical problems.
	Mathematical Manipulation	Students transform mathematical expressions accurately.
	Providing Justification	Students support their answers with logical, evidence-based reasoning.
	Drawing Conclusions	Students arrive at correct, generalizable conclusions from given data.

Data Analysis

This study employed quantitative and qualitative data analysis procedures following established mixed-methods research protocols for STEM education evaluation (Griffiths et al., 2021; Tuong et al., 2023). Given the pre-experimental one-shot case study design, descriptive statistics were deemed appropriate to provide preliminary insights into the module's potential effectiveness, as inferential statistical tests are not suitable for this research design (Creswell & Clark, 2017; Fraenkel et al., 2012; Plomp, 2013).

Validation scores from expert reviews were analyzed using Aiken's V formula to determine inter-rater reliability. A threshold value of 0.75 is considered acceptable for adequate agreement (Haryono et al., 2022; Ličen et al., 2023). This analysis ensured that the module met established quality standards before implementation.

Mathematical reasoning test results were analyzed using a comprehensive scoring framework specifically designed for STEM-based problem-solving. A three-point scoring

rubric was applied for each reasoning indicator, with final scores converted to percentages for clarity (Abd-El-Khalick et al., 2024). The detailed scoring criteria are presented in Table 3.

Table 3. Scoring criteria for the mathematical reasoning test

Indicator of Reasoning	Score 1 (Low)	Score 2 (Medium)	Score 3 (High)
Conjecturing	No attempt or irrelevant response	Attempted but unclear or only partially logical	Clear, logical, and well-grounded conjecture
Identifying patterns	Did not identify or misidentified pattern	Identified pattern but with minor errors	Correct and efficient pattern identification
Mathematical manipulation	Incorrect or incomplete manipulation	Partially correct, with some procedural steps missing	Correct and complete manipulation
Justification	No justification or incorrect explanation	Incomplete or partially relevant justification	Logical and fully relevant justification
Drawing conclusions	Incorrect or missing conclusion	Partially correct or unclear conclusion	Clear and accurate conclusion

Individual student scores were calculated by averaging their performance across all five reasoning indicators, converted to percentages, and categorized into achievement levels as shown in Table 4.

Table 4. Achievement level classification

Achievement Level	Score Range (%)	Description
Low	0–33%	Limited reasoning ability or incomplete understanding
Medium	34–66%	Partial or developing reasoning ability
High	67–100%	Strong, accurate, and well-justified reasoning

The five open-ended questions were adapted from validated instruments in previous STEM studies, with content validity confirmed through expert judgment and readability verified through pilot testing with a separate student group to ensure appropriateness for the target age group (Amalina & Vidákovich, 2022; English, 2023). Questionnaire responses were analyzed using descriptive statistics, including means and percentage distributions, to evaluate students' perceptions of the module's clarity, usability, and engagement with STEM-integrated mathematical content. The five-point Likert scale responses provided quantitative measures of student satisfaction and perceived effectiveness (Srikoon et al., 2024).

Interview data were analyzed using thematic analysis following Braun and Clarke's (2006) six-phase approach. A structured manual coding process identified recurring themes related to practicality, student engagement, and instructional challenges specific to STEM mathematics education (Tytler et al., 2023). The resulting themes were cross-referenced with questionnaire and test results to ensure consistency and strengthen interpretation validity through triangulation (Stanley & Robertson, 2024).

All quantitative and qualitative findings were integrated to comprehensively evaluate the module's validity, practicality, and effectiveness. This triangulated approach

ensured robust conclusions about the module's potential for enhancing mathematical reasoning in STEM contexts, particularly focusing on how students experience integrated STEM learning environments.

▪ RESULT AND DISCUSSION

Analysis Stage: Uncovering Needs and Designing Contextual Foundations

Initial classroom observations in a Grade 7 mathematics class revealed that 21 out of 30 students (70 percent) struggled to solve problems involving the addition or subtraction of fractions with different denominators. Many students applied procedures mechanically and could not explain the reasoning behind their steps, especially when converting to equivalent fractions. Interviews with two mathematics teachers confirmed this issue. One teacher stated that students often “just follow the steps on the board without understanding what they are doing.” This lack of conceptual understanding was also reflected in students’ difficulty justifying their answers and their limited participation during discussions. In one observed session, only six students actively engaged in problem-solving or asked clarifying questions. Teachers also noted that classroom instructional media were primarily static and unengaging. Students typically worked with printed worksheets or PowerPoint slides, which did not connect mathematical concepts to everyday experiences. These observations indicated low student involvement and minimal opportunity for developing reflective thinking or reasoning skills.

These findings are consistent with national and international research. Recent studies have shown that symbolic manipulation and procedural routines dominate mathematics classrooms, limiting students’ opportunities for critical thinking and conceptual understanding (Sevimli & Ünal, 2022). Likewise, research by Just and Siller (2024) and Goos et al. (2023) indicates that mathematics instruction frequently prioritizes formal procedures over contextual understanding. This instructional imbalance is particularly concerning in fraction operations, which demand flexible reasoning and the ability to generalize mathematical concepts (Ibrahim et al., 2024; Srikoon et al., 2024).

To address these issues, the nutritional content of packaged snack foods was selected as a contextual basis for the learning activities. This theme is familiar to students and provides authentic numerical data that can be explored through mathematical reasoning. Integrating real-life contexts such as sports or nutrition into STEM-based instruction has been shown to foster student motivation and improve the transfer of mathematical knowledge to everyday situations (Queiruga-Dios et al., 2025). Students are encouraged to observe, measure, compare, and draw conclusions in such settings. These activities are integral to inquiry-based learning and directly support the development of mathematical reasoning skills (Behnamnia et al., 2025; English, 2023).

To validate the relevance of the identified learning problems, data triangulation was applied using three sources: classroom observations, teacher interviews, and relevant literature. These data served as part of the initial formative evaluation within the ADDIE model, ensuring that the planned instructional design would address students’ real needs and be aligned with 21st-century competencies (Adeoye et al., 2024; Branch, 2009). Thematic analysis was used to examine qualitative data, following Braun and Clarke’s (2006) systematic steps for generating meaningful themes. As a result, three major issues were identified: conceptual gaps in fraction learning, lack of contextual learning resources, and weak support for reasoning and justification.

This analysis phase established a strong foundation for the design stage. It ensured that the instructional development was based on literature and grounded in classroom experiences. The findings informed the creation of a pedagogical design emphasizing meaningful and context-rich learning, essential in developing students' mathematical reasoning in real-world contexts.

Design Stage: Integration of Pedagogy, STEM, and Technology

The e-module was designed using the Engineering Design Process (EDP), which consists of seven stages: Define, Research, Plan, Create, Communicate, Redesign, and Evaluate. Each stage was deliberately structured to support students through contextualized and systematic problem-solving activities. This design also aimed to stimulate five core indicators of mathematical reasoning: making conjectures, identifying patterns, performing mathematical manipulations, providing justifications, and drawing conclusions (Chang et al., 2021; Tashtoush et al., 2024).

Within the context of snack food nutritional values, students engaged in identifying authentic problems such as calculating daily intake based on packaging information (Define), collecting relevant data from food labels (Research), planning strategies to solve mathematical tasks (Plan), conducting calculations (Create), presenting their reasoning and results (Communicate), and finally evaluating and refining their work (Evaluate). These learning processes provided integrated opportunities for scientific and mathematical thinking, strengthening cross-disciplinary competencies essential in STEM learning (Goos et al., 2023; Tuong et al., 2023).

The use of familiar real-life contexts, such as snack food, supports the principles of authentic learning. This approach emphasizes the relevance of connecting school mathematics with students' actual experiences, which can improve both engagement and conceptual understanding. These characteristics are also central to STEM literacy, where contextual relevance is considered a catalyst for meaningful learning (Guerra, 2024; Wang & Chen, 2025).

The EDP structure was selected for its alignment with inquiry-based learning. Prior research has shown that inquiry-based environments, especially those integrating digital tools, can enhance student motivation and cognitive processes (Antunes et al., 2023; Khalid et al., 2024). By embedding inquiry within familiar contexts, the design enabled students to approach abstract mathematical concepts with increased confidence and reflective thinking.

To ensure the quality of the e-module design, a validation process was conducted involving mathematics education experts and instructional technology specialists. The evaluation focused on contextual integration, task clarity, alignment with EDP stages, and support for reasoning development. Based on expert feedback, several improvements were made. These included simplifying the instruction flow, enhancing navigation through the digital interface, and refining the exploratory activities that target reasoning skills.

This design validation was part of the formative evaluation within the ADDIE instructional design model. Its primary aim was to ensure that the e-module accurately reflected students' learning needs and was pedagogically sound (Branch, 2009; Clark & Mayer, 2016). Exploration and context-based activities have increased student motivation and deeper cognitive engagement (Behnamnia et al., 2025; Tytler et al., 2023). Table 5

presents the instructional storyboard integrating the Engineering Design Process (EDP), STEM components, and mathematical reasoning indicators, as implemented in the e-module development.

Table 5. E-Module storyboard on fractions using EDP–STEM

EDP Stage	STEM Component	Student Activities	Cognitive Engagement	Mathematical Reasoning Indicators
Define	Science, Math	Identifying daily nutrition needs and reading food labels to define the problem.	Understanding the real-world problem	Making conjectures
Research & Imagine	Technology, Science	Collecting nutritional values from various snack products using online tools (e.g., FatSecret).	Investigating and hypothesizing	Recognizing patterns, generalizing
Plan	Engineering, Math	Planning strategies to calculate leftover nutritional needs.	Organizing problem-solving strategies	Designing arguments and modeling
Create	Math, Engineering	Solving fraction problems with real data; constructing menu alternatives.	Executing mathematical procedures	Applying operations, modeling with data
Communicate	Technology, Math	Presenting findings in digital slides or videos, and peer discussion.	Reflecting and explaining ideas	Communicating reasoning, justifying conclusions
Redesign	Engineering, Science	Revising menus based on peer feedback and balance.	Re-evaluating and improving designs	Revising arguments based on evaluation
Test & Evaluate	Math, Science	Taking post-module assessments to test understanding.	Testing conceptual comprehension	Verifying conclusions, validating strategies

Development Stage: Product Development and Expert Validity

The pedagogical design established in the previous stage was implemented in an interactive e-module format. Development was done using Canva for visual layout and Heyzine to convert the content into a flipbook format. This combination aimed to provide a more engaging and user-friendly digital learning experience. QR codes were integrated throughout the module to allow students access to external resources, including experiment videos and authentic nutritional data from packaged foods.

Several visual components, such as nutrition tables, food packaging illustrations, and contextualized problem prompts, were carefully included. These elements were intentionally designed to bridge the gap between abstract mathematical symbols and real-world representations that students can relate to. Visual literacy and numeracy integration

supported deeper conceptual understanding within technology-enhanced environments (Dominguez et al., 2023; Hähnlein et al., 2025). Figure 1 presents an example of this visual integration.



Figure 2. Example of a module page with image and data integration

As illustrated in Figure 2, the e-module integrates contextual visual elements with mathematical content to create an engaging learning experience. Rather than simply delivering information, the e-module was designed to encourage students to think critically and reflectively through contextualized mathematical reasoning. To ensure the quality and effectiveness of this approach, the developed product underwent rigorous evaluation by two mathematics education lecturers and one certified mathematics teacher. These experts assessed five key aspects: material feasibility, clarity of presentation, language appropriateness, practicality, and STEM integration. The comprehensive results of this validation process are presented in Table 6.

Table 6. Recapitulation of E-Module validation results

Aspects Assessed	Total Score	Max Score	Validity Index	Category
Material Eligibility	41	45	0.911	High Validity
Presentation Clarity	98	105	0.933	High Validity
Language Appropriateness	59	60	0.983	High Validity
Practicality	45	45	1.000	High Validity
STEM Integration	70	75	0.933	High Validity
Average	—	—	0.952	High Validity

These results demonstrate a strong level of content validity, consistent with prior research emphasizing the importance of combining pedagogical content, contextual visualizations, and digital media for effective instructional materials (Ličen et al., 2023; Shakeel et al., 2022).

Following the formative evaluation process recommended by the ADDIE model, the e-module underwent revisions based on expert input. These revisions included reorganizing concept maps to improve structure, simplifying problem wording to ensure accessibility, and enhancing visual elements such as color schemes and typography for better readability. These improvements aimed to ensure that the module was valid in

content and practical and inclusive in its design approach (Clark & Mayer, 2016; Ličen et al., 2023). After these adjustments, the e-module was ready for testing in classroom settings.

Implementation Stage: Testing Practicality and Learning Effectiveness

The implementation was conducted in phases through three testing schemes: one-to-one, small group, and field testing. Three students with different ability levels were involved in the one-to-one stage to evaluate individual usability and comprehensibility aspects. Practicality scores ranged from 81.05% to 95.78%, with an average of 86.66%, categorized as very practical. Students reported that the module was easy to understand and visually attractive. One student stated, "The modules are clear and interesting, especially the experimental part. I became enthusiastic about solving all the problems." However, feedback also revealed some confusion regarding the order of specific exploratory questions, particularly in activities involving nutritional data interpretation. In response, the e-module was revised by reordering the task flow within each subtopic so that narrative prompts, visual data, and symbolic tasks followed a clear and gradual progression. This refinement was expected to reduce cognitive load and improve user orientation, enhancing the module's practicality and eventual learning effectiveness during classroom implementation.

The small-group trial was conducted on six students. Five out of six participants scored above 80%, while one student (ERS) gave a practicality score of 68.42%, citing confusion when navigating between interactive pages. Interviews revealed that ERS faced difficulties related to unfamiliarity with digital tools. This highlighted the issue of unequal digital competence among students. This finding underscores the importance of addressing the broader challenge of the digital divide in educational technology implementation. Future iterations of the e-module should include adaptive onboarding features or short tutorial sessions to accommodate varying levels of digital literacy. Providing alternative formats or printed modules may also be considered to ensure equitable access, especially in resource-constrained environments (Howorth et al., 2024).

The final stage, the field test, was attended by 30 seventh-grade students over four meetings of 90 minutes each, conducted in an authentic classroom environment. Each session began with a brief orientation by the teacher, followed by independent exploration using the e-module through the Classkick platform, which enabled teachers to monitor and provide real-time feedback and annotations (Shin et al., 2023). This phased implementation approach was designed to support the development of students' mathematical reasoning in STEM learning environments integrated with technology (Ibrahim et al., 2024; Kong & Mohd Matore, 2021). Furthermore, the field trial also served as a basis for assessing module effectiveness using a pre-experimental one-shot case study design, where students were only given treatment without a pretest or control group, then directly measured using a mathematical reasoning post-test. This design was deemed appropriate for initial evaluation of learning innovation effectiveness in real classrooms (Creswell & Clark, 2017; Fraenkel et al., 2012), while aligning with formative evaluation practices in instructional design (Plomp, 2013; Tessmer, 1993).

Product Practicality Testing

Practicality testing was conducted in phases through three schemes: one-to-one, small group, and field test. The test results showed that the developed interactive e-module has a very high level of practicality. The practicality test results at the field test stage are presented in Table 7.

Table 7. E-Module practicality in field scale

Aspect	Score (%)	Category
Visual Design and Navigation	80.03	Very Practical
Interest and Motivation	82.25	Very Practical
Material Comprehension	85.03	Very Practical
STEM Context Connection	83.75	Very Practical
Average	82.76	Very Practical

Several students expressed that the module was easy to understand, visually attractive, and encouraged them to explore further. However, one student (ERS) scored the lowest (68.42%) in the small group stage. Based on interviews, this was due to limited digital literacy, reflecting the existence of a digital divide that requires attention in future product development (Howorth et al., 2024; Ličen et al., 2023).

Module Effectiveness on Mathematical Reasoning

The effectiveness of the e-module was measured through a post-test consisting of five context-based mathematical reasoning problems. Scores were categorized based on reasoning indicators developed in the e-module construction.

E-Module Effectiveness on Mathematical Reasoning

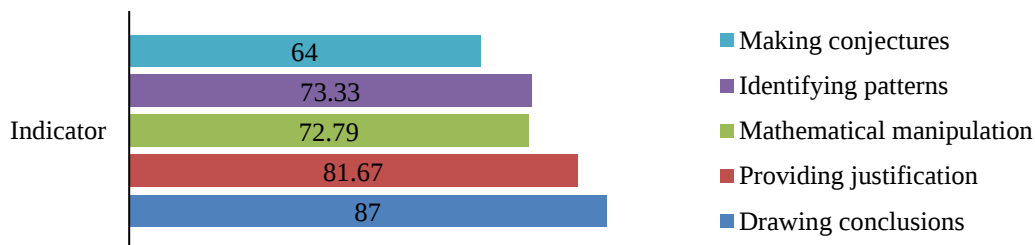


Figure 3. E-Module effectiveness on mathematical reasoning

The results showed that the e-module effectively improved students' mathematical reasoning abilities. The overall average from Figure 3 is 77.68, with a category high as indicated in Table 4. However, the "making conjectures" indicator recorded the lowest score among all indicators. This may be attributed to students' limited exposure to tasks requiring predictive reasoning and their unfamiliarity with constructing hypothetical assumptions. Students may need more structured support since such reasoning requires higher cognitive demand and is less common in routine classroom tasks. Instructional scaffolding, repeated modeling, and prompts encouraging exploration could help students strengthen their conjecturing skills in future lessons (Amalina & Vidákovich, 2022; Ghani et al., 2021).

Qualitative Analysis of Student Responses

A qualitative analysis of student responses was conducted to deepen the understanding of student learning processes. This analysis focused on how students represented their reasoning across five indicators: conjecturing, identifying patterns, mathematical manipulation, providing justification, and drawing conclusions. Below are two illustrative examples from students with different ability levels.

The image shows a handwritten student response for a high-ability student (MAR). The response is organized into five rows, each with a label in a box on the right and a corresponding handwritten note or calculation on the left. The labels are: 'conjecturing', 'identifying pattern', 'providing justification', 'mathematical manipulation', and 'drawing conclusions'. The handwritten text includes: 'Dik: $\frac{1}{3}$ kue keju', ' $\frac{1}{4}$ kue coklat', 'Ditanya: Berapa bagian total kue Dina?', 'Penjumlahan, penyebut berbeda disamakan 3', ' $\frac{1}{3} + \frac{1}{4} = \frac{4}{12} + \frac{3}{12} = \frac{7}{12}$ ', and 'jadi, total kue Dina adalah $\frac{7}{12}$ '.

Figure 4. Response of high-ability student (MAR)

Figure 4 shows the response of a high-ability student (MAR), who demonstrated all five indicators comprehensively. The student began by clearly stating the known and unknown information, showing the process of conjecturing. The operation used (addition of fractions) was explicitly written, indicating the identification of patterns. The student successfully transformed the fractions to equivalent forms with a common denominator (12), showing correct mathematical manipulation. Justification was provided through annotations and step-by-step reasoning. Finally, the conclusion was written correctly and concisely, completing the logical chain from problem comprehension to solution.

The image shows a handwritten student response for a medium-ability student (PRA). The response is organized into three rows, each with a label in a box on the right and a corresponding handwritten note or calculation on the left. The labels are: 'identifying', 'providing justification', and 'drawing conclusions'. The handwritten text includes: '1/3 kue keju di ubah menjadi 4/12 karena kue keju di kali kan 4/3 kpk dari 3 dan 4 adalah 12', '4 kue coklat di ubah menjadi 3/12 kue coklat di kalikan 3/4 total kue yg dimiliki Dina = 4/12 kue keju + 3/12 kue coklat', and '3 = 7/12 kue'.

Figure 5. Response of medium-ability student (PRA)

In contrast, Figure 5 shows the response of a medium-ability student (PRA). Although the final answer was mathematically correct, the student's reasoning process lacked formal structure. The response was largely narrative, with minimal mathematical symbols or equations. For example, instead of symbolizing fraction transformation, the student wrote: "1/3 cheesecake is changed to 4/12 because cheesecake multiplied by 4/4..." and continued with descriptive language. Interviews with PRA revealed that he perceived the problem as a story rather than a mathematical task. He explained, "Because it is about a cake, I imagined the story. I thought if I explained it like telling a story, it

would be correct." This suggests that PRA relied on intuitive contextual understanding rather than formal mathematical reasoning.

This contrast illustrates a critical gap between contextual comprehension and formal mathematical expression. Students like PRA may understand the problem narrative but lack the symbolic fluency to express their reasoning formally. Instructionally, this highlights the importance of explicitly bridging informal and formal reasoning during mathematics learning. Teachers are encouraged to scaffold students' use of symbolic language by providing structured modeling examples, guided practice, and reflective activities that connect real-life contexts with mathematical representations. Incorporating multiple representations and allowing peer discussion can further support students in transitioning toward more formal reasoning structures. These findings suggest that learning tools such as interactive e-modules should be designed to accommodate diverse reasoning styles while gradually fostering symbolic precision. By doing so, students will be better equipped to transform their understanding into mathematically valid arguments and solutions, thus deepening their conceptual learning (English, 2023; Tytler et al., 2023).

During the e-module implementation process, a formative evaluation was conducted to observe learning implementation dynamics and assess students' initial responses to the developed product. This evaluation included direct classroom observations, oral feedback from teachers, and process documentation through the Classkick platform, which enabled teachers to monitor student activities in real-time and provide direct intervention when necessary (Shin et al., 2023). Several initial challenges were identified in the one-to-one and small group stages, such as difficulties in page navigation and varying levels of student digital literacy. Feedback from teachers and students was used to make minor adjustments, such as simplifying technical instructions and adding navigation icons. These findings demonstrate that direct user involvement is crucial in the early implementation stages, as Tessmer (1993) suggested in tiered formative evaluation principles.

Furthermore, teachers conveyed that the integration of visual elements, contextual data, and interactive content in the module significantly increased student attention and motivation, aligning with reports by Dominguez et al. (2023) and Hähnlein et al. (2025) that emphasize the role of visual technology in enhancing learning engagement. However, a small group of students showed difficulties following activities due to limited technology access and low digital literacy. This condition reflects the presence of a digital divide in the implementation process, as also identified in previous studies addressing equity issues in technology-based learning (Crompton et al., 2024; Griffiths et al., 2021).

Findings from this formative evaluation were then used as a basis for improving the facilitation process in field testing, such as work time arrangements, teacher monitoring strategies, and providing scaffolding based on student needs. This evaluation became a key element in ensuring product readiness before the summative evaluation stage, and is consistent with ADDIE-based instructional development practice standards (Plomp, 2013; Tessmer, 1993).

Evaluation Stage: Synthesis and Reflection of Learning Product

The final evaluation stage was an integral part of the systematic approach in the ADDIE development model. Its purpose was to reflect and synthesize the quality of the

e-module across all development stages. Each phase underwent systematic and documented formative evaluation processes, from analysis to implementation. This aligns with the tiered evaluation principles in instructional development, as Tessmer (1993) and Plomp (2013) outlined.

Evaluation results showed quality consistency at each stage. The analysis stage successfully identified the learning needs in depth. The design stage successfully integrates pedagogical principles, STEM approaches, and Engineering Design Process syntax (Bertrand & Namukasa, 2023; Branch, 2009). Module development produced a digital product validated by experts with an average Aiken's V value of 0.952. This value indicates high agreement on content, language, presentation, practicality, and STEM integration. These results support the findings of Badaruddin et al. (2024), which emphasize the importance of synergy between content, technology, and authentic contexts in teaching material design.

In the implementation stage, data showed that the e-module had high practicality, with an average score of 82.76%. The module also demonstrated effectiveness in enhancing students' mathematical reasoning, reflected in an overall post-test average of 77.68%. No pretest data were collected as this study employed a one-shot case study design. Therefore, the effectiveness was interpreted solely based on post-test performance and was further substantiated by qualitative data and specific reasoning indicators. Validity, practicality, and effectiveness were mutually reinforcing: a validated design facilitated ease of use, while a practical product contributed to improved student learning outcomes. These findings are consistent with studies by Shakeel et al. (2022) and Licén et al. (2023), emphasizing that instructional design must integrate content relevance and functional usability to enhance learning success in digital environments.

Nevertheless, some findings need attention. Student scores on the "making conjectures" indicator remained moderate. This finding indicates the need for explicit learning strategies, such as scaffolding, to assist students in explorative and predictive reasoning processes (Amalina & Vidákovich, 2022; Stanley & Robertson, 2024). Additionally, one student encountered difficulties due to limited digital literacy and a lack of familiarity with interactive learning tools. This condition highlights the persistence of a digital divide in educational contexts, as discussed by Crompton et al. (2024) in their evaluation of technology use in instructional design.

Based on these evaluation results, several development recommendations can be presented. Future improvements include integrating onboarding features to support students' digital literacy, designing scaffolding mechanisms to assist explorative reasoning tasks, and preparing implementation guidelines informed by teacher feedback and classroom observations. It is advisable to conduct future testing using a quasi-experimental design with control and comparison groups to strengthen impact assessment. In addition, developing adaptive learning systems and using alternative rubrics incorporating multiple representations may help accommodate differentiated learning needs and encourage diverse forms of mathematical reasoning expression (Crompton et al., 2024; Shakeel et al., 2022).

This e-module meaningfully contributes to STEM-based mathematics learning by fulfilling three important aspects of teaching material development: validity, practicality, and effectiveness. This product exemplifies instructional development implementation

responsive to local needs, digital technology developments, and 21st-century learning challenges.

Implications for Learning Design, Pedagogical Practice, and Policy Development

The findings in this study offer comprehensive implications from theoretical, pedagogical, and systemic perspectives. From a learning design standpoint, the developed e-module shows that integrating the Engineering Design Process (EDP) within a STEM framework supports a structured yet flexible learning process. This structure encourages students to engage in real-world data exploration while fostering modeling-based reasoning, as Armutcu and Bal (2023) discussed. Such integration promotes epistemic agency by allowing students to construct and validate knowledge through authentic and meaningful tasks (Zhou et al., 2022).

In addition, the study reveals a precise alignment between the stages of the Engineering Design Process and specific indicators of mathematical reasoning. Students develop pattern recognition skills through contextual number analysis during the Ask and Define phases. The Research and Imagine stages encourage logical exploration and evaluation of possible strategies. Plan and Create foster analytical thinking through structured problem-solving, while Test and Improve promote evaluative reasoning through validation and revision. Lastly, the Share stage enhances communicative reasoning by requiring students to articulate and justify mathematical solutions (Ibrahim et al., 2024; Kong & Mohd Matore, 2021).

For teachers and education practitioners, the results of this study open up opportunities for applying similar development models to other mathematics topics such as percentages, proportions, statistics, or introductory algebra. These areas often involve contextual data and numerical exploration. With the support of digital technology, e-modules allow for experiential learning without overwhelming students with technical complexity, as highlighted by Ziatdinov & Valles (2022). However, successful implementation depends on effective teacher training. Teachers must be prepared to facilitate project-based and inquiry-driven learning, especially within the EDP framework. Professional development should include training in scaffolding during the Research phase, managing collaboration in planning, supporting peer feedback during testing, and fostering reflection throughout the design cycle. Without such preparation, as noted by Ibrahim et al. (2024), teachers may default to traditional methods even when using innovative tools. LMS-based platforms like SIMPKB or Learning House offer scalable opportunities for such training (Crompton et al., 2024).

From a policy perspective, this study reinforces the importance of strengthening numeracy literacy in national education strategies. Context-based and interdisciplinary e-modules can enhance students' cognitive engagement and improve performance on higher-order thinking tasks. This aligns with Ibrahim et al. (2024), who emphasized that STEM-based learning significantly supports students' mathematical numeracy abilities. However, challenges must also be acknowledged. Khalid et al. (2024) highlighted that disparities in access to digital learning tools remain a significant concern, especially in under-resourced educational settings. These perspectives underscore the importance of flexible and differentiated implementation strategies to ensure equitable access and effectiveness across diverse learning contexts.

Integration into national platforms can take several forms, such as embedding e-modules into systems like Learning House using standard APIs; creating teacher dashboards to monitor student progress and provide instructional guidance; developing adaptive assessments aligned with national standards but rooted in inquiry-based learning; and building analytics tools to inform policy decisions across regions (Tytler et al., 2023). Strategically, this e-module represents a model for adaptive learning tools that meet curriculum demands while enhancing cross-disciplinary competencies. It supports a transformative learning vision integrating mathematical skills, data literacy, and contextual understanding (Behnamnia et al., 2025). In this way, the study contributes meaningfully to education policy that champions responsive, technology-based learning.

Finally, the study reaffirms the potential of STEM as a pedagogical paradigm that fosters content integration and promotes systemic, multidisciplinary thinking. This aligns with global efforts toward competency-based education, where learners are expected to grasp concepts and apply them critically in real-life situations (Bertrand & Namukasa, 2023; English, 2023). Dominguez et al. (2023) further note that such approaches can enhance students' long-term retention and learning autonomy.

Limitations and Suggestions for Further Development

Although this study demonstrates promising results regarding validity, practicality, and its potential impact on students' mathematical reasoning, several limitations must be acknowledged. First, the implementation was confined to a single school and addressed only a fraction of the material within the specific context of nutritional value. Consequently, the generalizability of the findings is limited, as the effectiveness of digital learning tools often depends on contextual factors and student characteristics (Yuliardi et al., 2024). Nonetheless, this design was selected to facilitate early-stage validation of the instructional innovation in an authentic classroom context. Second, the study did not incorporate in-depth qualitative methods, such as think-aloud protocols or student reflections, essential for capturing students' reasoning processes during digital STEM-based activities (Stanley & Robertson, 2024). Such qualitative insights are particularly valuable for understanding how students interact with interactive content and construct meaningful knowledge.

Third, the e-module has yet to be evaluated within blended or fully remote learning environments. Given the increasing importance of flexible learning models in the post-pandemic educational landscape, this represents a critical gap. In addition, there is a potential novelty effect where students' initial enthusiasm for new technology may temporarily elevate motivation and performance without reflecting sustained conceptual understanding. It is important to examine this effect carefully to avoid confusing short-term gains with long-term learning outcomes (Behnamnia et al., 2025; Dominguez et al., 2023).

Future research should involve multiple implementation cycles across varied learning contexts to address these limitations, ideally employing longitudinal designs to assess enduring effects and reduce novelty bias. Further development could integrate adaptive learning features, such as real-time analytics and AI-driven feedback to enhance personalized instruction and formative assessment (J. Huang et al., 2025). Moreover, incorporating a familiarization phase before formal deployment may help distinguish authentic pedagogical impact from initial excitement (Zhexembinova et al., 2023). With

these enhancements, the e-module holds substantial potential to advance sustainable and flexible STEM-based mathematics education.

▪ CONCLUSION

This study aimed to develop and evaluate a STEM-based mathematics e-module using the ADDIE instructional design model to enhance junior high school students' mathematical reasoning abilities. The results showed that the e-module met the validity, practicality, and effectiveness criteria. Experts rated the module very valid across all assessment aspects, while classroom trials demonstrated its practicality and effectiveness, particularly in improving students' reasoning and conclusion-drawing abilities. This research provides strong empirical evidence that systematically integrating STEM approaches with instructional design models can produce relevant, contextual digital learning resources that foster higher-order thinking skills.

To support broader adoption and further development, several recommendations are proposed. It is recommended that the developed e-module be implemented more broadly in mathematics learning at junior high school and other educational levels. Teachers can adapt this module as an interactive and contextual teaching tool to improve the quality of STEM-based instruction. For further research, it is suggested to develop modules on mathematics topics with rich data connections and authentic contexts, such as percentages in economic settings, ratios in architectural modeling, statistics using demographic data, algebra linked to environmental variables, or geometry applied to engineering problems. Additionally, future studies should explore wider-scale implementations and investigate the long-term effects on students' reasoning and metacognitive skills. Emerging research questions include how EDP-based e-modules perform in diverse socioeconomic contexts, how to optimize implementation to maximize learning retention while minimizing novelty effects, and how individual learner differences influence module effectiveness.

Moreover, it is recommended to incorporate advanced learning technologies such as Augmented Reality (AR) and Artificial Intelligence (AI) to enhance the e-module's impact. For example, AR-based mobile manipulatives could improve spatial understanding of fractions and geometry. At the same time, AI-driven adaptive scaffolding could provide personalized feedback by analyzing real-time learning trajectories throughout the Engineering Design Process cycle. These integrations would further strengthen STEM-based digital learning by making it more engaging and responsive to individual needs.

Despite its contributions, this study has limitations. The e-module was tested only in a single school and focused exclusively on fractions within a nutritional context, limiting the findings' generalizability. The absence of longitudinal and qualitative data restricts understanding of the module's sustained effectiveness and the cognitive processes underlying students' reasoning. Therefore, further validation in diverse educational settings and across multiple mathematical topics is essential before recommending large-scale adoption. In conclusion, this study offers a replicable model for designing interdisciplinary, inquiry-based mathematics instruction aligned with twenty-first-century educational goals. Combining robust instructional design with digital tools paves the way for meaningful educational reform that can deliver relevant and engaging learning experiences for students in an evolving educational landscape.

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