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A STEM-BASED INTERACTIVE E-MODULE FOR STRENGTHENING STATISTICAL LITERACY IN MATHEMATICS LEARNING: DEVELOPMENT AND EVALUATION STUDY

Bintari Solafide Pasaribu[1]*, Abdul Hamid K.[2], R. Mursid[3]
[1*,2,3]Universitas Negeri Medan, Indonesia
*Corresponding author: fide5641@gmail.com[1], mursid@unimed.ac.id[3]

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Abstract

This study aimed to develop and evaluate a STEM-based interactive e-module to strengthen students' statistical literacy in mathematics learning. The study employed a Research and Development (R&D) approach using the ADDIE model, consisting of Analysis, Design, Development, Implementation, and Evaluation stages. The research was conducted at SMP Negeri 3 Medan involving 64 Grade VIII students, with 32 students in the experimental class and 32 students in the control class. The developed e-module integrated Science, Technology, Engineering, and Mathematics (STEM) principles with interactive multimedia features, including animations, videos, simulations, and contextual statistical problem-solving activities. The quality of the e-module was assessed through validity, practicality, and effectiveness evaluations. Expert validation results indicated that the e-module was highly valid, with scores of 86.43% from subject matter experts, 91.56% from media experts, and 95.63% from instructional design experts. Practicality testing showed positive responses from teachers (92.14%) and students (82.24%), indicating that the e-module was practical and easy to implement in classroom learning. The effectiveness evaluation revealed a significant improvement in students' statistical literacy. The average score increased from 58.00 on the pretest to 82.06 on the posttest. Furthermore, the N-Gain value reached 0.59, indicating a moderate improvement category, while Cohen's effect size of 0.93 demonstrated a large practical effect. Classical learning mastery reached 81.25%, and the independent-samples t-test showed a significant difference between the experimental and control groups ($p = 0.000 < 0.05$). These findings demonstrate that the STEM-based interactive e-module is valid, practical, and effective for enhancing students' statistical literacy and supporting meaningful mathematics learning in the digital era.

Keywords: ***STEM Education, Interactive E-Module, Statistical Literacy, Mathematics Learning, Digital Learning Technology***

INTRODUCTION

The rapid advancement of digital technology and the increasing demand for twenty-first-century competencies have transformed educational practices worldwide. Modern education emphasizes not only the acquisition of knowledge but also the development of higher-order thinking skills, problem-solving abilities, data literacy, and critical reasoning (OECD, 2023). In this context, mathematics education plays a strategic role in preparing students to interpret information, analyze quantitative data, and make evidence-based decisions. Among various mathematical competencies, statistical literacy has emerged as an essential skill due to the growing prevalence of data in everyday life, academic settings, and professional environments.

Statistical literacy refers to an individual's ability to understand, interpret, critically evaluate, and communicate statistical information presented in various forms, including tables, graphs, charts, and data reports (Gal, 2002). Garfield and Ben-Zvi (2008) emphasized that statistical literacy extends beyond computational proficiency and involves reasoning with data, identifying patterns, drawing conclusions, and evaluating statistical arguments. In the digital era, where information is increasingly data-driven, students are expected to possess adequate statistical literacy to navigate complex societal issues and make informed decisions.

Despite its importance, statistical literacy remains a significant challenge in many educational systems. The Programme for International Student Assessment (PISA) 2022 reported that Indonesian students continue to perform below the OECD average in mathematical literacy, particularly in interpreting data and solving real-world quantitative problems (OECD, 2023). Only a small proportion of Indonesian students demonstrated proficiency in applying mathematical concepts to contextual situations. These findings indicate that many students struggle to understand, analyze, and utilize statistical information effectively.

The challenges are also evident in classroom practices. Mathematics instruction in many schools remains predominantly teacher-centered, focusing on procedural calculations and formula memorization rather than conceptual understanding and data interpretation. Consequently, students often encounter difficulties in organizing data, interpreting graphical representations, identifying statistical relationships, and applying statistical concepts to real-life situations. Such learning conditions limit opportunities for students to develop meaningful statistical literacy skills. Educational technology offers promising opportunities to address these challenges. Digital learning resources, particularly interactive e-modules, have gained considerable attention as effective tools for facilitating independent, flexible, and engaging learning experiences. Interactive e-modules integrate multimedia elements such as animations, videos, simulations, interactive quizzes, and hyperlinks that can enhance learners' motivation and conceptual understanding (Mayer, 2021). Research has shown that interactive digital learning materials can improve students' mathematical achievement, engagement, and learning autonomy (Hwang et al., 2022; Krouska et al., 2023).

However, the effectiveness of digital learning resources depends largely on their pedagogical design. One instructional approach that has demonstrated considerable potential is STEM education, which integrates Science, Technology, Engineering, and Mathematics into authentic problem-solving experiences (Kelley & Knowles, 2016). STEM-based learning encourages students to connect theoretical concepts with real-world applications, engage in inquiry-based activities, and develop critical thinking skills. Recent studies have reported that STEM-oriented learning environments contribute positively to students' mathematical reasoning, creativity, and problem-solving abilities (Margot & Kettler, 2019; Thibaut et al., 2022). In mathematics education, STEM integration provides opportunities for students to explore statistical concepts through authentic investigations involving data collection, analysis, visualization, and interpretation. Such experiences can strengthen students' understanding of statistics while simultaneously fostering data literacy and analytical thinking. Nevertheless, despite the growing body of STEM-related research, the implementation of STEM-based digital learning resources specifically designed to improve statistical literacy remains limited.

Several previous studies have investigated the effectiveness of e-modules, STEM-based learning, and digital mathematics instruction. Arifin and Retnawati (2021) found that interactive e-modules improved students' conceptual understanding of mathematics. Banihashem et al. (2022) demonstrated that technology-enhanced learning environments could support students' learning engagement and achievement. Meanwhile, STEM-based instructional interventions have been shown to improve scientific literacy, critical thinking, and problem-solving skills (Nissa et al., 2021; Rilla et al., 2023). However, most existing studies focus on science education, physics, engineering projects, or general mathematics achievement rather than specifically targeting statistical literacy.

Furthermore, current studies often examine either digital learning media or STEM pedagogy independently. Limited research has integrated both approaches into a comprehensive interactive e-module designed explicitly to strengthen statistical literacy among junior high school students. This gap highlights the need for innovative instructional resources that combine digital technology, interactive learning features, and STEM principles within mathematics education. The novelty of this study lies in the development of a STEM-based interactive e-module specifically designed to enhance statistical literacy through contextual data-driven learning activities. Unlike conventional digital modules, the proposed e-module integrates STEM learning processes, multimedia interactivity, real-world statistical problems, self-assessment features, and inquiry-based activities that encourage students to engage actively in data interpretation and decision-making processes. The integration of STEM pedagogy with interactive digital learning resources represents a novel contribution to mathematics education, particularly in fostering statistical literacy competencies among junior high school students.

Therefore, this study aims to develop and evaluate a STEM-based interactive e-module for mathematics learning. Specifically, the objectives of this study are: (1) to develop a STEM-based interactive e-module for statistical learning; (2) to examine the validity of the developed e-module through expert evaluation; (3) to assess its practicality based on teacher and student responses; and (4) to evaluate its effectiveness in improving students' statistical literacy. The findings are expected to contribute to the advancement of digital mathematics education and provide an innovative instructional solution for strengthening students' statistical literacy in the era of data-driven learning.

LITERATURE REVIEW

Statistical Literacy

Statistical literacy is recognized as an essential competency in the twenty-first century because individuals are increasingly required to interpret and use data in daily life. According to Gal (2002), statistical literacy refers to the ability to understand, interpret, critically evaluate, and communicate statistical information. This competency extends beyond performing calculations and includes making informed decisions based on data. Garfield and Ben-Zvi (2008) further emphasized that statistical literacy involves understanding statistical concepts, interpreting graphical representations, identifying patterns, and drawing meaningful conclusions from data.

The Organisation for Economic Co-operation and Development (OECD, 2023) identifies statistical literacy as an important component of mathematical literacy. Students are expected to analyze data, interpret statistical information, and apply quantitative reasoning to solve real-world problems. Therefore, developing statistical literacy is a critical objective of mathematics education, particularly at the junior high school level. In this study, statistical literacy is conceptualized through five indicators: (1) understanding and identifying data, (2) organizing and presenting data, (3) analyzing data using statistical measures, (4) interpreting statistical results, and (5) evaluating statistical information critically.

STEM Education

STEM (Science, Technology, Engineering, and Mathematics) education is an interdisciplinary approach that integrates knowledge and skills from multiple disciplines to solve authentic problems (Kelley & Knowles, 2016). STEM learning encourages students to engage in inquiry, investigation, design thinking, and problem-solving activities that connect classroom learning with real-life situations. The theoretical foundation of STEM education is rooted in constructivist learning theory, which emphasizes active knowledge construction through meaningful experiences (Piaget, 1972; Vygotsky, 1978). Through STEM activities, students are encouraged to apply scientific reasoning, utilize technology, develop engineering solutions, and employ mathematical concepts in integrated contexts. Previous studies have demonstrated that STEM-based learning improves students' critical thinking, creativity, problem-solving abilities, and academic achievement (Margot & Kettler, 2019; Thibaut et al., 2022). In mathematics learning, STEM provides meaningful contexts for exploring statistical concepts through data collection, analysis, visualization, and interpretation activities. Consequently, STEM education offers a promising framework for strengthening students' statistical literacy.

Interactive E-Modules in Mathematics Learning

Interactive e-modules are digital learning resources that combine multimedia elements such as text, images, videos, animations, simulations, and interactive assessments within a self-directed learning environment. According to Mayer's (2021) Cognitive Theory of Multimedia Learning, students learn more effectively when information is presented through multiple channels that support cognitive processing. Interactive e-modules offer several advantages, including flexibility, accessibility, learner autonomy, and immediate feedback. These features can enhance students' motivation and engagement while supporting deeper conceptual understanding. Hwang et al. (2022) reported that digital learning materials significantly improve students' learning outcomes and engagement. Similarly, Krouska et al. (2023) found that interactive digital environments facilitate active learning and increase learner participation. In mathematics education, interactive e-modules are particularly valuable because they can visualize abstract concepts and provide opportunities for exploration and practice. Statistical concepts such as data representation, measures of central tendency, and data interpretation can be presented more effectively through interactive multimedia features.

STEM-Based Interactive E-Modules for Statistical Literacy

The integration of STEM education and interactive e-modules provides a powerful approach to enhancing statistical literacy. STEM-based interactive e-modules allow students to engage with authentic data, apply statistical concepts in real-world contexts, and utilize digital technologies to support learning. Such integration promotes active learning, critical thinking, and problem-solving skills while fostering meaningful understanding of statistics. Several studies have shown positive effects of STEM-based instructional materials on students' literacy and higher-order thinking skills (Nissa et al., 2021; Rilla et al., 2023). However, most previous research has focused on science education, engineering projects, or general mathematics achievement. Research specifically examining STEM-based interactive e-modules for improving statistical literacy remains limited.

Research Gap

Although previous studies have reported the effectiveness of STEM learning and digital learning resources, several gaps remain. First, most studies focus on mathematics achievement rather than statistical literacy. Second, STEM interventions are often implemented in science-related subjects rather than statistical learning. Third, limited studies have integrated STEM pedagogy and interactive e-modules into a single learning resource specifically designed for junior high school mathematics. Therefore, this study addresses these gaps by developing and evaluating a STEM-based interactive e-module aimed at strengthening students' statistical literacy. The integration of STEM principles, multimedia interactivity, and contextual statistical investigations represents an innovative approach to supporting mathematics learning in the digital era.

METHOD

Research Design

This study employed a Research and Development (R&D) approach to develop and evaluate a STEM-Based Interactive E-Module designed to strengthen students' statistical literacy in mathematics learning. The study adopted the ADDIE instructional design model developed by Branch (2009), which consists of five systematic phases: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was selected because it provides a comprehensive framework for developing educational products while ensuring continuous revision and quality improvement throughout the development process. The research focused on three major product quality indicators, namely validity, practicality, and effectiveness. The validity aspect examined the appropriateness of content, instructional design, and media quality. Practicality referred to the usability of the e-module from teachers' and students' perspectives, while effectiveness was measured through improvements in students' statistical literacy achievement.

Research Setting and Participants

The study was conducted at SMP Negeri 3 Medan, Indonesia, during the 2025/2026 academic year. The participants consisted of: (1) Three expert validators, including: One mathematics content expert; One instructional design expert; and One educational technology and media expert; (2) Two mathematics teachers who participated in practicality evaluation; and (3) Sixty-four Grade VIII students selected through cluster random sampling: Experimental Group (Class VIII-B): 32 students; and Control Group (Class VIII-A): 32 students. The experimental group received instruction using the STEM-Based Interactive E-Module, whereas the control group learned using conventional teaching materials and teacher-centered instruction.

Development Procedure

Analysis Phase.

The analysis phase aimed to identify instructional problems, learner characteristics, curriculum requirements, and learning resource needs. Data collection activities included: Classroom observations; Teacher interviews; Student questionnaires; and Curriculum document analysis. The findings revealed several instructional challenges. Students demonstrated difficulties in understanding statistical concepts, interpreting data presented in tables and graphs, determining measures of central tendency, and applying statistical reasoning in real-life contexts. Teachers also reported limited availability of interactive digital learning resources capable of promoting statistical literacy. Furthermore, analysis of students' learning preferences indicated a strong interest in technology-supported learning environments and interactive digital materials. Therefore, a STEM-based interactive e-module was considered an appropriate solution to address these instructional needs.

Design Phase

The design phase focused on developing the instructional blueprint of the e-module. The following components were designed: Learning objectives; Statistical literacy indicators; STEM learning activities; Module structure and navigation; Multimedia elements; Assessment instruments; and Learning scenarios.

The e-module content was developed based on the Grade VIII mathematics curriculum, particularly the statistics unit covering: Data collection; Data representation; Frequency tables; Bar charts and line graphs; Mean; Median; Mode; and Data interpretation.

Table 1. The instructional design integrated STEM principles as follows:

STEM Component	Learning Activity
Science	Observing and collecting real-world data
Technology	Using digital media and interactive tools
Engineering	Designing solutions and interpreting findings
Mathematics	Analyzing and evaluating statistical data

The learning activities were organized according to inquiry-based and problem-solving approaches to encourage active engagement and critical thinking.

Development Phase

The development phase involved producing the STEM-Based Interactive E-Module using multimedia technologies. The module included: Interactive text explanations; Infographics; Animations; Instructional videos; Interactive exercises; Self-assessment quizzes; Immediate feedback systems; and Reflection activities. After the prototype was completed, expert validation was conducted to assess the quality of the product. The validation covered: (1) Content Validation. Evaluation criteria included: Content accuracy; Curriculum alignment; Conceptual clarity; Statistical literacy relevance; and STEM integration; (2) Instructional Design Validation. Evaluation criteria included: Learning objectives; Learning activities; Student engagement; Assessment suitability; and Instructional sequence.; (3) Media Validation. Evaluation criteria included: User interface design; Navigation; Multimedia quality; Interactivity; and Accessibility. The experts provided recommendations and revisions that were incorporated into the final product before implementation.

Implementation Phase

The validated e-module was implemented in the experimental classroom over six instructional meetings. Students accessed the e-module through laptops and smartphones during classroom learning and independent study sessions. Learning activities followed the STEM learning sequence: Problem identification; Data collection; Data organization; Data analysis; Interpretation of findings; and Reflection and communication The control group received conventional mathematics instruction using textbooks and teacher explanations. Throughout implementation, observations were conducted to monitor student participation, engagement, and learning activities.

Evaluation Phase

Evaluation was conducted both formatively and summatively. Formative evaluation occurred during development and expert review processes, while summative evaluation assessed product validity, practicality, and effectiveness after implementation.

Research Instruments

Expert Validation Questionnaires. Validation questionnaires used a five-point Likert scale. The instruments assessed:Content quality; Learning design quality; and Media quality. Practicality Questionnaires. Teacher and student questionnaires evaluated: Ease of use; Clarity of instructions; Learning attractiveness; Accessibility; and Overall satisfaction. Statistical Literacy Test. The effectiveness instrument consisted of pretest and posttest assessments measuring statistical literacy. The test indicators included: Understanding and identifying data; Organizing and presenting data; Analyzing statistical information; Interpreting statistical results; and Critically evaluating statistical information. Prior to implementation, the test underwent validity and reliability testing. Observation Sheets. Observation sheets recorded: Student engagement; Participation levels; Classroom interactions; and Learning implementation fidelity.

Data Analysis

Validity Analysis. The validity score was calculated using percentage analysis.

Table 2. Validity criteria

Percentage	Category
81–100%	Very Valid
61–80%	Valid
41–60%	Fair
≤40%	Invalid

Practicality Analysis. Practicality data from teachers and students were analyzed using descriptive percentages.

Table 3. Practicality criteria

Percentage	Category
81–100%	Very Practical
61–80%	Practical
41–60%	Fair
≤40%	Impractical

Effectiveness Analysis

Normalized Gain (N-Gain). Improvement in statistical literacy was measured using N-Gain.

Table 4. Normalized Gain (N-Gain) criteria

N-Gain	Category
>0.70	High
0.30–0.70	Moderate
<0.30	Low

Independent Samples t-Test. An independent samples t-test was conducted to examine differences between the experimental and control groups. Decision criteria: $p < 0.05$ = significant difference; $p \geq 0.05$ = no significant difference.

Effect Size. Cohen's d was calculated to determine the magnitude of the treatment effect.

Table 5. Effect Size Interpretation

Effect Size	Interpretation
0.20	Small
0.50	Medium
≥0.80	Large

Success Criteria

The STEM-Based Interactive E-Module was considered successful if: Expert validation scores exceeded 80%; Teacher and student practicality scores exceeded 80%; Classical learning mastery reached at least 75%; N-Gain was in the moderate or high category; Statistical significance was achieved ($p < 0.05$); Effect size was greater than 0.80.

Ethical Considerations

Ethical approval and permission were obtained from the school administration prior to conducting the study. Participation was voluntary, and informed consent was obtained from teachers, students, and parents. Confidentiality and anonymity of participants were maintained throughout the research process. All collected data were used exclusively for academic and research purposes.

RESULTS AND DISCUSSION

Results

Development of the STEM-Based Interactive E-Module

The development process followed the ADDIE model, consisting of Analysis, Design, Development, Implementation, and Evaluation stages. The final product was a STEM-based interactive e-module designed to support statistical literacy learning in Grade VIII mathematics. The module integrated multimedia elements, including instructional videos, animations, interactive exercises, STEM investigation activities, and self-assessment features.

Validity Results

The quality of the developed e-module was evaluated by three experts: a content expert, an instructional design expert, and a media expert. The validation results are presented in Table 6.

Table 6. Expert Validation Results

Validator	Percentage (%)	Category
Content Expert	86.43	Very Valid
Media Expert	91.56	Very Valid
Instructional Design Expert	95.63	Very Valid
Average	91.21	Very Valid

The average validation score of 91.21% indicates that the e-module met the criteria of a highly valid instructional product and was suitable for classroom implementation.

Practicality Results

Practicality evaluation was conducted through teacher and student questionnaires after implementation.

Table 7. Practicality Results

Respondent	Percentage (%)	Category
Teacher	92.14	Very Practical
Students	82.24	Practical
Average	87.19	Very Practical

The results demonstrate that both teachers and students perceived the e-module as easy to use, attractive, and supportive of learning activities.

Effectiveness Results

Effectiveness was evaluated through students' statistical literacy achievement.

Table 8. Statistical Literacy Achievement

Assessment	Mean Score
Pretest	58.00
Posttest	82.06

The average score increased by 24.06 points after students used the STEM-based interactive e-module.

N-Gain Analysis

The N-Gain analysis was conducted to determine the magnitude of learning improvement.

Table 9. N-Gain Results

Indicator	Value
N-Gain	0.59
Category	Moderate

The N-Gain value of 0.59 indicates a moderate improvement in students' statistical literacy.

Hypothesis Testing

An independent-samples t-test was performed to compare the achievement of students in the experimental and control groups.

Table 10. Independent Samples t-Test

Variable	Sig. (2-tailed)
Statistical Literacy	0.000

Since $p < 0.05$, there was a statistically significant difference between students who learned using the STEM-based interactive e-module and those who learned through conventional instruction.

Effect Size Analysis

The magnitude of the intervention effect was measured using Cohen's d.

Table 11. Effect Size

Effect Size (d)	Category
0.93	Large

The effect size of 0.93 indicates that the e-module had a substantial impact on improving students' statistical literacy.

Discussion

The findings demonstrate that the STEM-based interactive e-module successfully met the criteria of validity, practicality, and effectiveness. The high validation scores obtained from content, instructional design, and media experts indicate that the developed product possesses strong pedagogical and technological quality. This finding supports Branch (2009), who emphasized that systematic instructional design contributes significantly to the quality of educational products. The high validity scores obtained from content, instructional design, and media experts indicate that the developed STEM-based interactive e-module possesses strong pedagogical and technological quality. These findings are consistent with the study conducted by Mursid, Saragih, and Hartono (2022), which demonstrated that the integration of multimedia technology and project-based learning significantly improved instructional quality and student learning outcomes in engineering education. Their findings emphasized that well-designed digital learning environments provide meaningful learning experiences, enhance student engagement, and support the development of higher-order thinking skills. Therefore, the strong validation results obtained in this study suggest that the developed e-module successfully integrates STEM principles, statistical literacy content, and interactive multimedia elements into a coherent instructional framework (Mursid et al., 2022).

The practicality results suggest that the e-module was well accepted by both teachers and students. The integration of multimedia components, interactive activities, and user-friendly navigation facilitated independent learning and increased learner engagement. These findings are consistent with Mayer's (2021) Multimedia Learning Theory, which states that meaningful learning occurs when verbal and visual information are integrated effectively. The practicality results indicate that both teachers and students perceived the e-module as easy to use, attractive, and beneficial for learning. This finding supports the research of Mursid, Muslim, and Farihah (2023), who reported that collaborative e-learning models significantly improve student participation, digital literacy, critical thinking, and learning engagement. Their study highlighted that technology-supported learning environments encourage students to actively construct knowledge, collaborate with peers, and access diverse learning resources. Similarly, the STEM-based interactive e-module developed in this study provided students with opportunities to explore statistical concepts independently while engaging in interactive and inquiry-oriented learning activities. Such learning experiences contribute to greater motivation and more meaningful learning outcomes (Mursid et al., 2023).

The significant improvement in statistical literacy achievement confirms the effectiveness of the STEM-based interactive e-module. The increase in mean scores from 58.00 to 82.06 and the moderate N-Gain score (0.59) indicate that students developed a better understanding of statistical concepts and data interpretation skills after using the module. This result aligns with previous studies by Hwang et al. (2022), who reported that interactive digital learning materials positively affect students' academic performance. The significant increase in students' statistical literacy achievement demonstrates the effectiveness of integrating STEM pedagogy into mathematics learning. Students were actively involved in collecting, organizing, analyzing, and interpreting real-world data, enabling them to connect statistical concepts with authentic contexts. This finding aligns with the study by Halimatussa'diah, Sitompul, and Mursid (2024), which found that collaborative and reflective learning models significantly improved

student achievement by emphasizing planning, collaboration, scientific inquiry, and critical reflection. The authors argued that student-centered learning environments facilitate deeper conceptual understanding and foster essential twenty-first-century competencies. Likewise, the STEM-based e-module in this study promoted analytical reasoning, problem-solving, and evidence-based decision-making, which are fundamental components of statistical literacy (Halimatussa'diah et al., 2024).

The positive impact can also be attributed to the STEM integration embedded within the learning activities. Through authentic data collection, analysis, and problem-solving tasks, students were able to connect statistical concepts with real-world contexts. According to Kelley and Knowles (2016), STEM learning environments encourage interdisciplinary thinking and improve learners' ability to apply knowledge in practical situations. Another important finding of this study is the effectiveness of technology-enhanced learning in promoting flexible and meaningful learning experiences. The integration of digital media, interactive assessments, and authentic STEM tasks enabled students to learn both independently and collaboratively. This result is supported by the work of Uzir, Siagian, and Mursid (2025), who reported that mobile technology-based learning models significantly improved student learning outcomes, motivation, and engagement. Their findings suggest that digital learning innovations provide greater accessibility and flexibility while supporting student-centered instructional practices. Therefore, the success of the developed e-module further confirms the potential of technology-integrated learning environments in enhancing mathematics education and preparing students with essential competencies for the data-driven society of the twenty-first century (Uzir et al., 2025).

Furthermore, the significant t-test result ($p = 0.000$) and the large effect size ($d = 0.93$) demonstrate that the intervention produced meaningful educational benefits. The large effect size suggests that the observed improvement was not only statistically significant but also practically important. This finding supports research conducted by Thibaut et al. (2022), who concluded that integrated STEM learning positively influences higher-order thinking skills and academic achievement. Another important finding is that the e-module promoted active learning. Students were not merely recipients of information but actively participated in collecting, organizing, analyzing, and interpreting data. Such experiences are essential for developing statistical literacy because they require learners to engage in critical reasoning and evidence-based decision making. These competencies are increasingly important in contemporary data-driven societies (OECD, 2023). Overall, the results indicate that integrating STEM pedagogy with interactive digital learning resources provides an effective strategy for strengthening statistical literacy in mathematics education. The developed e-module not only improved students' learning outcomes but also fostered engagement, critical thinking, and meaningful learning experiences. Therefore, the STEM-based interactive e-module can serve as an innovative instructional resource for supporting mathematics learning in junior high schools.

CONCLUSION

This study successfully developed a STEM-Based Interactive E-Module to strengthen students' statistical literacy in mathematics learning. Using the ADDIE development model, the e-module was systematically designed, validated, implemented, and evaluated to ensure its instructional quality and effectiveness. The findings indicate that the developed e-module achieved a high level of validity, as demonstrated by expert validation scores from content experts (86.43%), media experts (91.56%), and instructional design experts (95.63%), with an overall average of 91.21%, categorized as very valid. These results confirm that the e-module is pedagogically sound, technically appropriate, and aligned with curriculum requirements. The practicality evaluation also revealed positive outcomes. Teacher responses reached 92.14%, while student responses reached 82.24%, indicating that the e-module is practical and user-friendly. The integration of multimedia elements, interactive activities, and STEM-based learning tasks contributed to increased engagement and facilitated independent learning.

Furthermore, the effectiveness analysis demonstrated that the e-module significantly improved students' statistical literacy. The average score increased from 58.00 on the pretest to 82.06 on the posttest. The N-Gain value of 0.59 indicated a moderate level of improvement, while the independent-samples t-test showed a statistically significant difference between the experimental and control groups ($p < 0.05$). In addition, the effect size value of 0.93 reflected a large educational impact of the intervention. The novelty of this study lies in the integration of STEM pedagogy, interactive multimedia technology, and statistical literacy development within a single digital learning resource. The e-module provides authentic, data-driven learning experiences that encourage students to analyze, interpret, and evaluate statistical information in meaningful contexts. Overall, the STEM-Based Interactive E-Module is a valid, practical, and effective instructional resource for enhancing statistical literacy among junior high school students. The findings contribute to the advancement of digital mathematics education and provide evidence

for the potential of STEM-integrated learning technologies in supporting twenty-first-century competencies, particularly data literacy, critical thinking, and problem-solving skills.

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