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Developing an interactive e-book integrating pedagogical deep learning and local wisdom to enhance digital literacy and mathematical critical thinking

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Abstract

This study aimed to develop and evaluate an interactive e-book integrating deep learning principles with Garut local wisdom to enhance digital literacy and mathematical critical thinking. Using a research and development (R&D) approach with the ADDIE model and a quasi-experimental design, 73 seventh-grade students participated: 36 in the experimental group and 37 in the control group. Data were collected through mathematical critical thinking tests, digital literacy questionnaires, and expert validation sheets, then analyzed using normalized gain scores, the Mann-Whitney U test, and Cohen's d. The e-book achieved very high validity (93.33%) and practicality ratings exceeding 95%. The experimental group demonstrated significantly greater gains in mathematical critical thinking (Ng = 0.89) than the control group (Ng = 0.70), with a Cohen's d of 2.59 indicating a very strong effect. Additionally, 95.35% of students reported improved digital literacy. These findings indicate that culturally grounded interactive e-books can effectively enhance 21st-century skills, providing a replicable framework for integrating local wisdom in mathematics education across diverse cultural contexts.

Keywords: interactive e-book; deep learning; local wisdom; digital literacy; mathematical critical thinking

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Introduction

The 21st century marks the pervasive involvement of technology in nearly every aspect of human life. Technological innovations are developing at a faster pace every day, introducing new technologies that impact various aspects of students' lives, from how they communicate, play, socialise, and learn. The introduction of the internet into daily activities has also changed their reading habits and patterns, encouraging students to increasingly integrate technology into their academic activities (Weisberg, 2011). Technology has enormous potential to improve the quality of learning, as it has been proven to improve learning outcomes and increase student engagement (Karabatzaki et al., 2018).

The use of technology is necessary in every learning activity, including mathematics (Jupri et al., 2015). The didactic triangle is refined into a didactic tetrahedron to emphasize the role of artefacts and technology as integral components of mathematical learning, alongside teachers, students, and mathematical content (Tall, 1986). Technology in mathematics learning can enhance education quality (Tchoshanov, 2013), and help reduce the abstractness of mathematical concepts, stimulating active and creative learning activities (Papadakis et al., 2016).

One form of technology integration in learning is the use of e-books. E-books are publication presented in digital form and accessible through electronic devices (Davidson & Carliner, 2014). E-books present information in an interactive multimodal format, including written text, voice narration, music, illustrations, animations, and more. E-books offer advantages over printed books, including ease of access, flexibility (Makwanya & Oni, 2019), and enhanced interactivity (López-Escribano et al., 2021). Research has demonstrated that e-books can facilitate literacy development, sometimes more effectively than printed books (López-Escribano et al., 2021).

Digital literacy refers to the ability to access, understand, evaluate, create, and communicate information effectively through digital technology. In Indonesia, this competency remains underdeveloped. Based on data from the Ministry of Communication and Information, Indonesia's digital literacy index is still categorized as moderate (Kemkominfo, 2024), with junior high school students experiencing particular difficulties (Hernawan et al., 2021; Zaenudin et al., 2020).

Not only is digital literacy still suboptimal, but other crucial skills to develop in the 21st century, such as critical thinking, are also lacking (Anggo et al., 2021). Critical thinking is the ability to think reflectively and logically, focusing on deciding what to believe and do, whether it be ideas or actions (Dominguez et al., 2015; Ennis, 1993). Based on the results of the 2018 PISA, students encountered various difficulties on the test, which was designed to measure higher-order thinking skills (HOTS). These skills include analysis, evaluation, problem-solving, reasoning, and decision-making, all of which are essential components of critical thinking. These results indicate that Indonesian students still face challenges in mathematical critical thinking (Erlita & Hakim, 2022; Rohmah et al., 2023).

One of the reasons why digital literacy and critical mathematical thinking skills are not optimal is the weak competence of teachers in Indonesia (De Ree et al., 2019). E-books are

considered suitable for implementation in current-generation learning to improve digital literacy (Kistofer et al., 2019). In mathematics learning, e-books are needed to facilitate learning. Printed books cannot visualise abstract material more concretely (Setiyani et al., 2022), whereas e-books can be creatively created to make mathematics more tangible. E-books can also facilitate different learning speeds by allowing for easier review of material (Logan et al., 2021).

E-book design can focus on developing students' critical thinking skills in mathematics and be integrated with local wisdom to enhance relevance to students' daily lives and increase learning motivation (Prahmana & D'Ambrosio, 2020). Such integration is aligned with global educational perspectives that emphasize contextual and place-based learning, as reflected in UNESCO's vision of education grounded in local realities while addressing global challenges (UNESCO, 2021). The learning approach can also be integrated according to goals and needs, such as with deep learning.

Deep learning is a learning process that actively engages students in meaningful tasks based on real-life contexts and experiences close to their own, to develop 21st-century competencies such as critical thinking, creativity, collaboration, communication, and digital literacy. This learning takes place through a partnership between students and educators, with digital technology supporting meaningful learning (Fullan et al., 2018; Voogt & Roblin, 2012). In educational contexts, deep learning is conceptualized as a learning approach that emphasizes meaning-making, profound conceptual understanding, and the ability to connect and transfer knowledge across contexts, thereby extending beyond rote memorization or surface-level learning (Kovač et al., 2025).

There are changes in the education curriculum in Indonesia in the 2025/2026 academic year, namely by using a deep learning approach (*pembelajaran mendalam*). Three principles in deep learning, namely (1) joyful learning where learning must emphasize the creation of a safe, positive, and motivating learning atmosphere for students; (2) meaningful learning, where learning must encourage the connection of material with real experiences and teacher-student collaboration; and (3) empowering learning, where learning must provide space for students to be independent, creative, and utilize technology to strengthen competencies. It is important to note that deep learning in this study refers to a pedagogical approach that promotes meaningful, reflective, and transformative learning experiences (Fullan et al., 2018;), and should not be confused with deep learning in artificial intelligence or machine learning contexts.

Despite the growing body of research on interactive e-books in mathematics education, studies that integrate deep learning pedagogy with local cultural wisdom to simultaneously develop digital literacy and mathematical critical thinking remain scarce, particularly in Southeast Asian contexts (Spante et al., 2018). Existing studies often focus on either technological features or cultural integration separately, without examining their combined effects on higher-order thinking skills. Drawing from ethnomathematics and culturally responsive pedagogy frameworks (Prahmana & D'Ambrosio, 2020; Rahmawati et al., 2021), this study addresses this gap by integrating local cultural wisdom with interactive digital learning. Garut, a regency in West Java, Indonesia, possesses rich cultural heritage in traditional crafts (e.g., *batik* patterns), food production (e.g., *dodol* calculation), and economic practices

that provide authentic contexts for mathematical problem-solving. This cultural integration aligns with the ethnomathematics perspective that recognizes mathematics as culturally embedded and seeks to connect formal mathematics with students' cultural experiences. This study aims to develop an interactive e-book integrating deep learning pedagogy and Garut local wisdom to enhance digital literacy and mathematical critical thinking skills.

Methods

Research design

This study employed a mixed-methods developmental research approach, which combines product development and effectiveness evaluation. The development phase aimed to produce a deep learning-based e-book integrated with Garut local wisdom, while the effectiveness phase was conducted to examine its impact on students' digital literacy and mathematical critical thinking skills. This approach in accordance with established educational design research (EDR) frameworks that emphasize iterative product design and empirical validation (Akker et al., 2013; Richey & Klein, 2014).

This research design uses the ADDIE development model as part of an educational design research framework to guide the systematic development and refinement of the instructional product. The ADDIE model is recommended for development research because it provides a comprehensive structure for designing and developing multimedia-based learning products (Akker et al., 2013; Hanafi et al., 2020). The stages are Analysis, Design, Development, Implementation, and Evaluation (Wahyuni et al., 2020). The detailed stages of the ADDIE model are presented in Figure 1.

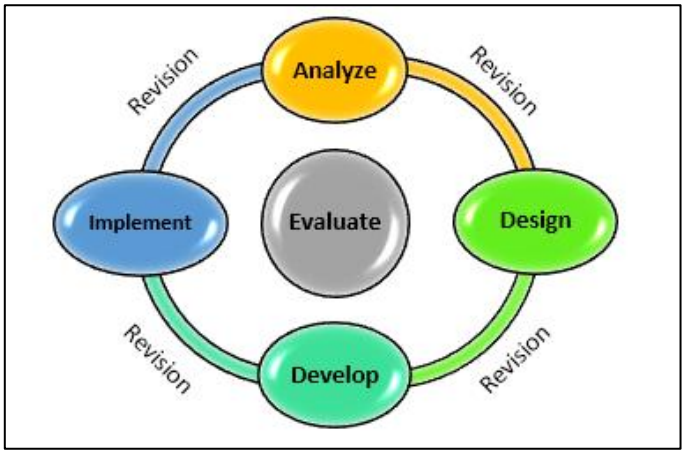

Figure 1. Stage of the ADDIE instructional design model

Participants

A total of 73 seventh-grade students from a junior high school in Garut Regency participated in the research. The students were selected through a convenience sampling strategy involving two intact classes. The Experimental Group consisted of 36 students who utilized the interactive e-book, while the Control Group comprised 37 students who received conventional instruction.

To minimize initial differences, class assignment was conducted through matching based on students' general academic ability and prior records. The intervention was implemented over 2 weeks, consisting of 4 instructional sessions (each 80 minutes), with students in the experimental group using the interactive e-book throughout all learning activities. Prior to data collection, informed consent was obtained from all participating students and their parents/guardians. The school principal also provided institutional permission for conducting the research. Students were informed that their participation was voluntary and that they could withdraw at any time without penalty.

Instruments

The study utilized several instruments to collect data on validity, practicality, and effectiveness, aligned with each research question. The Mathematical Critical Thinking Test was a performance-based assessment consisting of seven descriptive items adapted from the FRISCO framework (Focus, Reasons, Inference, Situation, Clarity, Overview). This instrument achieved a Cronbach's alpha of 0.802, indicating high reliability. Digital literacy was measured through self-report questionnaires where students evaluated their perceptions of digital competencies after using the e-book. While self-report measures have inherent limitations, including potential social desirability bias, they remain widely used in educational research to capture learners' perceived competencies and attitudes (Spante et al., 2018). This approach was deemed appropriate given the study's focus on students' perceived improvement rather than objective skill measurement. Future studies may benefit from incorporating performance-based digital literacy assessments for triangulation. Validation and Practicality Sheets were used to gather expert ratings and user feedback on product quality.

Table 1. Product validity and practicality criteria: (a) validity criteria; (b) practicality criteria.

(a) validity criteria

Criteria	Validity Score
Very valid	85.01%-100.00%
Valid	70.01%-85,00%
Fairly valid	55.01%-70,00%
Less valid	37.01%-55,00%
Invalid	20.00%-37.00%

(b) practicality criteria

Category	Percentage
Very practical	85.01%-100.00%
Practical	70.01%-85,00%
Quite practical	55.01%-70,00%
Less practical	37.01%-55,00%
Impractical	20.00%-37.00%

Procedure and intervention duration

The implementation stage involved the experimental group using the deep learning-based interactive e-book during mathematics lessons to solve contextual problems. The intervention was implemented over a period of 2 weeks, totaling 4 instructional meetings, with each session lasting 80 minutes. Prior to the intervention, both groups completed a pretest to assess their baseline mathematical critical thinking skills. During the intervention, students in the experimental group engaged with the e-book's interactive features, including hyperlinks to external resources, embedded videos, and contextual problems based on Garut local wisdom.

Meanwhile, the control group received conventional instruction using standard textbooks. After the intervention, both groups completed a posttest using the same instrument. Additionally, students in the experimental group completed questionnaires to assess their perceptions of digital literacy improvement and the practicality of the e-book.

Data analysis

Quantitative analysis focused on determining the magnitude of student improvement through the Normalized Gain (N-gain) score. The Mann–Whitney U Test was selected for inferential statistics because the N-gain data followed a non-normal distribution, making a non-parametric test necessary to validly compare the experimental and control groups. Finally, Cohen's d was calculated to determine the strength of the intervention, yielding a value of 2.59, which represents a very strong effect.

Results

The result of this research is an interactive e-book that integrates deep learning with local wisdom from Garut to enhance digital literacy and critical mathematical thinking skills. Based on feasibility and practicality testing, the e-book was declared feasible by subject matter experts and learning media experts. The following describes the steps taken to produce a feasible e-book.

Analysis stage

The analysis phase encompasses needs analysis, curriculum analysis, and an examination of student characteristics. The results of the analysis serve as the starting point for product planning. The needs analysis begins by identifying the urgency of digital literacy and critical thinking skills in mathematics. The analysis shows that digital literacy and mathematical critical thinking skills are key 21st-century competencies that students must possess. Both skills are necessary for both the learning process and daily life.

Digital literacy is essential for students to search, comprehend, and critically evaluate information in the rapidly evolving digital landscape. Moreover, digital literacy also fosters creativity, collaboration skills, and effective communication skills by utilising various digital platforms. Beyond this, digital literacy instils ethical awareness and responsibility in the use of technology, enabling students to become smart, safe, and productive users of the digital world. Mathematical critical thinking skills are essential for students because they enable them not only to understand mathematical concepts but also to analyse, evaluate, and solve problems logically and systematically. Through mathematical critical thinking skills, students are trained to connect mathematical knowledge to everyday life problems, analyse arguments and solutions, and make accurate decisions based on data and evidence. In addition, mathematical critical thinking also contributes to the development of independent learning, strengthens reasoning skills, and equips students with the 21st-century competencies needed to face the increasingly complex challenges of the digital age.

Therefore, both digital literacy and mathematical critical thinking skills are crucial for continued development. Equally important, the results indicate that the achievement of both skills remains suboptimal. If left unchecked, this condition will contribute to students receiving invalid information, as they are unable to properly analyse and evaluate it, leading to errors in their knowledge construction.

Based on the analysis, one of the causes of suboptimal digital literacy and mathematical critical thinking skills is weak teacher competency and learning that is still focused on conventional learning methods. There are not many interactive media that teachers can create to support learning activities. One crucial aspect is the use of textbooks in learning. Books, as learning resources, are generally still in the form of printed, rigid, and traditional textbooks. This leaves students focused solely on the textbook and lacking motivation to engage in literacy activities that expand their knowledge and understanding.

Based on the previous analysis, it is clear that students need more engaging and interactive books to support their learning, such as e-books. Students also need to focus on digital literacy and critical mathematical thinking skills. Therefore, an interactive e-book based on deep learning, integrated with local wisdom from Garut, was developed to enhance digital literacy and critical mathematical thinking skills.

Building on this, the curriculum analysis began with an examination of the current junior high school curriculum, which includes the 2013 Curriculum (revised) and the Independent Curriculum (*Kurikulum Merdeka*). Both emphasise conceptual mastery, logical thinking skills, problem-solving, and the ability to relate mathematics to everyday life (Kemendikbud, 2017; Kemendikbudristek, 2022). The mathematics content for junior high school includes numbers, algebra, geometry, statistics, probability, and relations and functions.

The analysis shows that the number material is placed in grade VII as an initial foundation. This material requires mastery not only procedurally but also contextually through solving real-life problems. This aligns with the curriculum's direction, which encourages the development of critical, creative, and collaborative thinking skills, as well as digital literacy (OECD, 2018). The material was selected for this study based on several key considerations. First, number is a fundamental concept that serves as a prerequisite for other mathematical topics, such as algebra, geometry, statistics, and probability, and a good mastery of it facilitates students' understanding of subsequent material (Kilpatrick et al., 2001). Second, the concept of number is highly contextual as it frequently appears in students' daily lives, for example, calculating discounts, determining ratios, or calculating profit and loss, which helps students understand the real benefits of mathematics (Rohmah et al., 2023). Third, number material has strong potential for digital literacy development as it can be easily visualized through interactive media, such as digital number lines and e-book-based simulations (UNESCO, 2019).

Beyond these foundational aspects, number material also encourages critical thinking through contextual problems where students can be trained to analyze, compare solution strategies, and evaluate results (Facione, 2011). Additionally, numbers can be linked to Garut local wisdom through the economic and cultural activities of the local community, such as calculating the cost of raw materials for making *dodol* (a traditional Indonesian sweet),

discounts on local products, or vendor profits, which makes learning more meaningful and fosters an appreciation for local culture.

Building on this, the curriculum analysis revealed that digital literacy and critical thinking skills are core competencies at all levels of education. Further analysis was conducted to address issues related to digital literacy and mathematical critical thinking skills at the junior high school level, in accordance with the needs analysis. The findings revealed that junior high school students encounter various obstacles in developing digital literacy and critical thinking skills in mathematics. The curriculum analysis concluded that effective learning media are needed to facilitate the development of digital literacy and mathematical critical thinking skills in junior high school students.

Student characteristics were analysed through interviews with several junior high school mathematics teachers in Garut Regency. The results revealed that students generally exhibit low levels of digital literacy and critical thinking skills. They tend to only listen to teacher explanations and are reluctant to explore. Their interest in the learning process is also quite low. These findings indicate that interactive and engaging learning media are necessary to stimulate students' exploration. The analysis stage informed the direction of product development. Researchers developed an interactive e-book as the learning media. The e-book was grounded in deep learning principles and integrated with Garut local wisdom. The design process utilized the Canva application for content creation and Flip Builder for interactive visualization. This product aimed to improve students' digital literacy and mathematical critical thinking skills.

Design stage

The analysis results guided the design phase. The e-book was designed using the Canva application and visualized using Flip Builder. The activity began with selecting an A4 document format. The fonts used were TAN *Tangkiwood* and Garet for the cover, and Open Sans for the body text, in sizes ranging from 14 to 16 points. The e-book was created by typing directly into the Canva application, allowing for immediate visualization of the final product. The e-book structure includes the cover, foreword, introduction, table of contents, learning outcomes, learning objectives, concept map, learning trajectory, and detailed number topics. The design was grounded in deep learning principles integrated with Garut local wisdom, focusing on digital literacy and mathematical critical thinking skills. The e-book can be used in conjunction with teachers during mathematics lessons or accessed independently via computer or smartphone.

The introductory section of the e-book explains Garut and its local wisdom. This section provides initial context and introduces students to the geographical, social, and cultural background of Garut. Students not only read the core material but also understand the real-world context of Garut society, which later serves as examples in the mathematical content. This section also fosters an appreciation for local wisdom. Culture is often overlooked over time and needs to be continually promoted and nurtured. The section builds a sense of pride and appreciation for Garut culture, especially among students. The review of local wisdom in the introduction makes students aware that the traditions and values of the Garut community

remain relevant in modern life, including in the digital context. The introduction also includes various hyperlinks within the text. This embedding trains student to explore digital information sources, compare information from various sources, and develop digital literacy and critical thinking skills when selecting information. Moreover, the introduction serves as a bridge from the real world to the e-book material. Students begin with a topic close to their heart (Garut and local culture), then are guided to broader mathematical concepts in subsequent chapters. The language in the introduction is designed to be engaging, fostering student engagement and curiosity.

The next section is the table of contents, which outlines the e-book structure. Each section in the table of contents is provided with navigation links to the material. This design facilitates hierarchical learning from beginning to end. Students can also review specific material by selecting the section they deem necessary. After the table of contents, the learning outcomes and objectives are explained to reinforce the direction of the learning process. Next, there is a concept map and a learning trajectory. These components provide a comprehensive overview of the content and discussion flow, enabling students to easily understand the relationships between sections and the position of each sub-topic within the overall framework. Through this visualization, students are helped to navigate the book contents, develop structured thinking skills, and see the connections between the concepts learned. The concept map supports the principle of deep learning, as students are encouraged to build deep understanding through connections between ideas. This aligns with the curriculum goal of emphasizing meaningful learning, where connected knowledge structures help students become more critical, reflective, and prepared for real-life contexts. In the learning trajectory, students can study key aspects of the number system, including its history, rational numbers, and exponents. This section also includes embedded links, allowing students to explore the material of their choice in greater depth. The presentation begins with a contextual problem containing local wisdom from Garut. Students are then challenged to think critically, presented with concepts, and engaged in collaborative problem-solving.

This learning series aligns with the three pillars of deep learning: meaningful learning, mindful learning, and joyful learning. Students are encouraged to build deeper understanding through the process of proving, seeking alternative answers, generalizing, and solving problems. The local wisdom context makes mathematics more relevant to students' real lives, while encouraging them to think critically, reflectively, and creatively. The language used is communicative and engaging, making the learning experience enjoyable, relevant, and meaningful.

Development stage

The designed e-book then entered the development phase. The first step involved a feasibility test, validated by material and media experts. Six material and media experts stated that, in terms of material and media, the e-book was deemed highly valid, with a 93.33% validity rate. Likewise, other instruments, such as the mathematical critical thinking instrument, were validated for content and face validity by three material experts and were declared highly valid,

with a 91.43% face validity rate and a 96.19% content validity rate. Although the validation results were excellent, several improvements were also noted by the media experts. Therefore, the e-book was revised in accordance with the suggestions of media experts, as outlined in Table 2.

Table 2. Revisions of the interactive e-book based on media expert input.

Media Expert Notes	Before Revision	After Revision
The cover was less colorful and less attractive for junior high school students; the e-book title was too long	The cover used dark colors and a long, formal title that was less engaging for junior high school students	The cover was redesigned using brighter colors, contextual illustrations representing local wisdom of Garut, and a shorter, more student-friendly title
The overall appearance was too formal and not engaging for junior high school students	The content layout was text-dominant with a formal design style	The layout was redesigned to be more visual and interactive, incorporating icons, illustrations, and more communicative language
The presentation of topics lacked clear emphasis and structure	Learning materials were presented without visual emphasis on main topics and subtopics	Visual emphasis was added through colored headings, icons, and clear hierarchical structure of topics
There was no learning pathway to guide students' understanding	The material was presented linearly without an overview of learning progression	A learning pathway page was added to help students understand the sequence and relationships among concepts
There was no table of contents and page navigation	The e-book did not include a table of contents	An interactive table of contents and page numbering were added to improve navigation
There was no learning evaluation such as quizzes	No quizzes or formative assessments were provided	Interactive quizzes were added at the end of each section to evaluate students' understanding

Implementation stage

After the e-book was deemed feasible, it was piloted with a group of 36 students at a public junior high school in Garut Regency, forming the experimental group. The e-book was implemented during the learning process. For comparison, a control group of 37 students was also involved in this study, which was conducted without the use of the e-book. Both groups were given a pretest before the learning process to determine their initial mathematical critical thinking skills, and a posttest to determine their achievement and improvement in mathematical critical thinking skills. Specifically, in the experimental class, student response sheets were provided regarding the e-book, digital literacy, and practicality sheets for both teachers and students. Figure 2 is a description of the learning activities.

Figure 2. Learning activities using the deep learning-based e-book

The data collected from the research was then analyzed using the Mann-Whitney test to examine differences in mathematical critical thinking skills between the experimental and control groups. The pre-test results showed that there was no significant difference in initial critical thinking skills between the two groups (Figure 3a), indicating that both groups had comparable baseline abilities prior to the intervention. In contrast, the post-test results revealed a statistically significant difference in critical thinking skills between the experimental group and the control group (Figure 3b), with the experimental class demonstrating substantially better mathematical critical thinking abilities than the control class.

Test Statistics[a]

	Nilai
Mann-Whitney U	645.000
Wilcoxon W	1.348E3
Z	-.256
Asymp. Sig. (2-tailed)	.798

a. Grouping Variable: Kelas

(a) pretest

Test Statistics[a]

	Nilai
Mann-Whitney U	50.000
Wilcoxon W	753.000
Z	-6.864
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Kelas

(b) post-test

Figure 3. Mann Whitney test results: (a) pretest; (b) post-test.

Furthermore, the N-Gain analysis indicated a significant difference in the improvement of mathematical critical thinking between the experimental and control groups (Figure 4). The experimental class showed a notably higher increase (Ng = 0.89 ± 0.07) compared to the control class (Ng = 0.70 ± 0.07), with Cohen's d of 2.59, indicating a very strong effect. Consequently, the e-book is considered effective in improving students' mathematical critical thinking skills.

Test Statistics[a]

	N_Gain
Mann-Whitney U	48.500
Wilcoxon W	751.500
Z	-6.854
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Kelompok

Figure 4. Mann Whitney N-Gain results

Additionally, the student response questionnaire also revealed that 98.07% of students showed very positive responses toward the e-book, and 95.35% reported that the e-book was very effective in improving their digital literacy. Regarding practicality, the e-book received very practical ratings from both students (97.57%) and teachers (95.31%). These percentages were obtained by averaging the scores across all questionnaire items and converting them into percentages of the maximum possible score.

Evaluation stage

The e-module has completed a series of stages, including analysis, design, development, and implementation, in accordance with the ADDIE process. The e-module has been tested and analysed for validity, practicality, and effectiveness. It has also been revised based on expert and user suggestions to improve its quality. The e-module has fulfilled its purpose as a good learning resource.

Discussion

This study extends the existing literature on deep learning pedagogy and ethnomathematics by demonstrating how these frameworks can be synergistically integrated within interactive digital environments. While previous research has examined technology-enhanced learning and culturally responsive pedagogy separately, our findings suggest that combining these approaches produces stronger effects on mathematical critical thinking than either approach alone. The substantial effect size (Cohen's d = 2.59) observed in this study exceeds typical findings in educational technology research (Hillmayr et al., 2020), suggesting that the integration of pedagogical principles with cultural contextualization creates a multiplicative rather than merely additive effect on learning outcomes.

In a similar vein, students in the experimental class demonstrated greater improvements in mathematical critical thinking skills than those in the control group. This finding suggests that the deep learning-based interactive e-book may contribute to the development of students' analytical, evaluative, and reflective thinking processes. Similar patterns have been reported in prior research, indicating that context-based and interactive digital learning environments are positively associated with students' critical thinking development in mathematics (Hermita et al., 2022; Nguyen et al., 2021).

Context-based and interactive digital learning environments are positively associated with the development of students' mathematical critical thinking, including analytical,

evaluative, and reflective thinking, as demonstrated by studies employing context-rich problems, problem-based learning, flipped or digital-enabled pedagogy, and interactive multimedia tools in mathematics education (Nurdin et al., 2023; Suryawan et al., 2023). This body of work aligns with broader educational theory that learner-centered, technology-enhanced contexts foster higher-order thinking in mathematics across diverse mathematical domains (Cîrneanu, Andrada-Livia Moldoveanu, 2024; Syahfitri & Safitri, 2024).

The positive responses from both students and teachers further support the potential practicality and usability of the developed e-book. Most students perceived the e-book as practical and helpful for engaging with digital information, while teachers reported that it was easy to implement in classroom settings. These findings align with previous studies suggesting that interactive e-books are associated with enhanced digital literacy practices, such as information exploration, critical evaluation, and collaboration in digital environments (Damyanov & Tsankov, 2018). Through the use of hyperlinks, simulations, and contextual problems, the developed e-book provides opportunities for integrating digital literacy with mathematical critical thinking in a complementary manner.

Taken together, the findings indicate that the development of a deep learning-based interactive e-book integrating Garut local wisdom has the potential to create meaningful, engaging, and contextually relevant learning experiences. In line with Eppard et al., 2021, the incorporation of local wisdom in digital learning media may not only enhance learning relevance but also support students' cultural awareness in navigating the digital era. Digital learning that integrates local wisdom is most effective when it engages community participation, utilizes local contexts, and balances digital with non-digital practices. Community co-design ensures cultural and epistemological relevance (Aguayo & Eames, 2017), while culturally grounded digital media enhance engagement and understanding (Andriani et al., 2023). Collaborative online integration of local knowledge further strengthens cultural awareness and learning outcomes (Tindowen et al., 2023). Preserving non-digital elements also supports accessibility and sustains tangible local practices (Smith & Aguayo, 2022).

The findings of this study are aligned with recent meta-analytic evidence on digital learning in mathematics education. According (Hillmayr et al., 2020), in their comprehensive meta-analysis of 92 studies, found that digital tool use had a significant positive effect on student learning outcomes in secondary school mathematics ($g = 0.65$, $p < .001$). Similarly, (Zhao et al., 2021) demonstrated that gamified interactive e-books significantly improved students' mathematics performance, motivation, and metacognition tendency compared to conventional flipped learning and traditional instruction. A systematic mapping study confirmed that interactive e-books enhance mathematics learning by providing multimedia resources, interactive questions, and immediate feedback (Jácome-Guerrero et al., 2023).

However, our findings also align with research suggesting that technology alone is insufficient for developing higher-order thinking skills. (Puig et al., 2020), in their systematic review of e-learning environments for critical thinking, emphasized that successful interventions require explicit instructional design features that promote active engagement and reflection. Similarly, (Zainuddin et al., 2020) noted in their study that gamification without appropriate pedagogical frameworks may lead to poor learning outcomes. This is congruent

with (Wang & Abdullah, 2024), which concluded that critical thinking development requires instructors to identify specific objectives and employ flexible teaching strategies.

The substantial effect size observed in this study (Cohen's d = 2.59) exceeds those reported in previous meta-analyses. This discrepancy may be attributed to our explicit integration of deep learning principles, which provided the pedagogical scaffolding often missing in purely technology-focused interventions. The combination of joyful, meaningful, and empowering learning experiences with culturally relevant contexts appears to have created a synergistic effect that enhanced both engagement and critical thinking development.

The three principles of deep learning (joyful, meaningful, and empowering learning) were operationalized in the e-book design. Joyful learning was achieved through interactive features, colorful visuals, and game-like quizzes. These elements created a positive learning atmosphere. Meaningful learning was facilitated by embedding mathematical concepts within authentic local contexts. Examples include calculating profits from *dodol* production and determining ratios in *batik* patterns. This contextualization enabled students to connect abstract concepts with their lived experiences. Empowering learning was supported by hyperlinks, embedded videos, and self-paced navigation features. These tools gave students autonomy over their learning journey.

Despite the promising findings, this study has several limitations that should be acknowledged. First, the sample size was relatively small (N = 73) and drawn from a single school, which may limit the generalizability of the results. Second, the intervention was conducted over a relatively short period, and no long-term retention test was administered to examine the sustainability of the observed learning gains. Third, the possibility of a Hawthorne effect cannot be ruled out, as students may have been influenced by their awareness of participating in a research study. In addition, teacher-related variables, such as instructional style and classroom management, were not explicitly measured or controlled. Therefore, future studies are recommended to involve larger and more diverse samples, longer intervention durations, longitudinal assessments, and more rigorous controls of instructional variables to further validate the findings.

Conclusion

This study demonstrates that interactive e-books integrating deep learning pedagogy with local cultural wisdom can effectively enhance both digital literacy and mathematical critical thinking among junior high school students. The key to success lies not in technology alone, but in the thoughtful integration of meaningful cultural contexts, interactive features, and evidence-based pedagogical principles that together create transformative learning experiences. This study offers several implications. For research, future studies should employ randomized controlled trials with larger and more diverse samples, longer intervention durations, and longitudinal designs to examine learning retention and establish causal relationships. Replicating this framework across different cultural contexts would provide valuable insights into the generalizability of culturally grounded digital learning innovations. For practice, mathematics teachers can adopt the design principles demonstrated in this study, which combine joyful,

meaningful, and empowering learning with local cultural contexts, to develop engaging digital learning materials that simultaneously address multiple 21st-century competencies. For policy, educational stakeholders should consider supporting the development of culturally responsive digital learning resources that bridge global pedagogical frameworks with local wisdom, particularly in diverse cultural settings across Southeast Asia and beyond.

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Declarations

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