Journal of Honai Math, 9(1), 25-42, April 2026
https:/doi.org/10.30862/jhm.v9i1.984

Supporting collaborative and creative mathematical thinking through a multimodal digital textbook: Design and evaluation of a wordwall-integrated learning environment

Arie Anang Setyo *, Ania Yulita Sipahelut, Irna Rusani

Mathematics Education Department, Muhammadiyah University of Sorong, Sorong, Indonesia

* Correspondence: arieanangsetyo.ums@gmail.com

Received: 1 July 2025 | Revised: 16 April 2026 | Accepted: 30 April 2026 | Published: 30 April 2026
© The Authors 2026

Abstract

Traditional mathematics instruction has often been insufficient in fostering essential twenty-first-century competencies, particularly students' collaborative and creative thinking skills. Addressing this challenge, this study aimed to develop and evaluate a Wordwall-integrated multimodal digital mathematics textbook designed to enhance these competencies among elementary school students. The development process was guided by the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) instructional design framework. Following expert validation, the textbook was implemented using a one-group pretest–posttest design involving 20 fourth-grade students. Data were collected through expert validation instruments, practicality questionnaires, collaboration observation rubrics, and a standardized creative thinking assessment. The validation results demonstrated a high level of feasibility across media (95%), content (90%), and instructional design (92%) dimensions. Practicality evaluations further indicated highly positive responses from teachers and students, with an overall mean score of 95.5%. Effectiveness analysis revealed notable improvements in students' learning outcomes and twenty-first-century competencies, with collaboration skills reaching a high category (70.0%) and creative thinking skills showing moderate improvement (N-gain = 0.60). Furthermore, posttest scores were significantly higher than pretest scores ($p < .001$), indicating meaningful learning gains following the intervention. These findings suggest that Wordwall-integrated multimodal digital textbooks can serve as an effective instructional resource for promoting collaborative and creative thinking skills in elementary mathematics education and provide empirical support for the integration of multimodal and gamified learning environments in mathematics classrooms.

Keywords: Collaborative skills; Creative thinking; Elementary mathematics education; Multimodal digital textbook; Wordwall

Introduction

The development of twenty-first-century competencies has become a central objective of contemporary mathematics education, reflecting the increasing demand for learners who are capable of collaborating effectively, thinking creatively, and solving complex problems in dynamic learning environments (Voogt & Roblin, 2012). Among these competencies, collaborative and creative thinking have received particular attention because they enable students to construct mathematical understanding through social interaction, generate multiple solution strategies, and adapt their reasoning to novel situations. In elementary mathematics education, these competencies are especially important, as early learning experiences play a critical role in shaping students' cognitive flexibility, communication skills, and dispositions toward mathematical inquiry. Despite their recognized importance, instructional practices in many primary school classrooms continue to be dominated by teacher-centered approaches that emphasize procedural knowledge transmission and individual task completion. Such practices are frequently supported by static printed textbooks and limited opportunities for student interaction, thereby constraining learners' active participation in knowledge construction and reducing opportunities to engage in meaningful mathematical discourse (Afrila & Yarmayani, 2018). Consequently, the development of higher-order cognitive and social competencies remains insufficiently supported within many elementary mathematics learning environments (Mawaddah, 2022).

Recent advances in educational technology have created opportunities to redesign mathematics learning environments in ways that better support active engagement and competency development (Ghavifekr & Rosdy, 2015). In particular, multimodal digital learning resources have emerged as a promising instructional innovation because they combine textual, visual, auditory, and interactive representations within a unified learning environment (Mayer, 2021). The integration of multiple representational modes is consistent with established cognitive perspectives suggesting that mathematical understanding is strengthened when learners can access and coordinate information across diverse modalities (Imansari & Sunaryantiningsih, 2017). Through interactive and multimodal presentations, digital textbooks can facilitate conceptual understanding, increase learner engagement, and promote deeper exploration of mathematical ideas. Empirical studies have demonstrated that multimodal digital resources contribute positively to students' motivation, participation, and learning outcomes by providing more accessible and meaningful learning experiences than traditional instructional materials.

Beyond multimodal representation, the integration of gamified learning platforms has further expanded the pedagogical potential of digital learning resources. One platform that has gained considerable attention in educational settings is Wordwall, which enables teachers to design interactive learning activities through game-based formats that encourage participation, immediate feedback, and repeated engagement with mathematical content. Gamification elements embedded within Wordwall can support active learning processes by encouraging students to interact with learning materials, collaborate with peers, and experiment with alternative problem-solving strategies. Such features have been associated with increased

motivation, improved classroom participation, and enhanced opportunities for creative exploration (Ghavifekr & Rosdy, 2015). Consequently, integrating Wordwall into multimodal digital textbooks offers the potential to transform mathematics learning from a predominantly receptive process into a more interactive and socially mediated experience that promotes both collaborative engagement and creative reasoning.

Nevertheless, important limitations remain within the existing literature. Although multimodal digital textbooks and gamified learning platforms have each been examined in previous studies, research has largely focused on their contributions to content delivery, learner engagement, or procedural achievement outcomes. Comparatively less attention has been devoted to the intentional design of instructional resources that explicitly target the development of twenty-first-century competencies, particularly collaborative and creative thinking (Leikin & Pitta-Pantazi, 2013; Voogt & Roblin, 2012). Furthermore, studies investigating digital textbooks and Wordwall-based learning have generally examined these approaches independently rather than integrating them within a coherent pedagogical framework (Dichev & Dicheva, 2017; Oliveira et al., 2021). As a result, limited empirical evidence is available regarding how multimodal representations, gamified interactions, and structured collaborative learning tasks can be systematically combined to support students' social and cognitive development in mathematics classrooms. In addition, research simultaneously examining the validity, practicality, and effectiveness of such integrated instructional resources remains scarce, particularly within elementary mathematics education contexts where the cultivation of collaborative and creative competencies is increasingly emphasized.

Addressing these gaps requires the development of instructional resources that move beyond the use of technology as a mere medium for content delivery and instead position technology as a pedagogical scaffold for meaningful learning (Ghavifekr & Rosdy, 2015; Mayer, 2021). Drawing upon this perspective, the present study develops and evaluates a Wordwall-integrated multimodal interactive digital textbook designed specifically for elementary mathematics education. The textbook was conceptualized as an integrated learning environment that combines multimodal content presentation, gamified learning activities, and structured collaborative tasks aligned with established indicators of collaborative and creative thinking (Dichev & Dicheva, 2017; Leikin & Pitta-Pantazi, 2013; Oliveira et al., 2021). To ensure systematic development and evaluation, the study adopted the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) instructional design framework, which provides a comprehensive process for designing, implementing, and assessing educational interventions.

Accordingly, this study pursues three primary objectives. First, it seeks to develop and validate a Wordwall-integrated multimodal digital textbook that satisfies established standards of content quality, media design, and instructional effectiveness. Second, it examines the practicality of the developed textbook through teacher and student responses during classroom implementation. Third, it evaluates the effectiveness of the textbook in enhancing students' collaborative skills and creative thinking through observational assessments and pretest–

posttest normalized gain (N-gain) analysis. By integrating principles of multimodal learning, gamification, and instructional design within a single pedagogical framework, this study contributes to the growing body of research on technology-enhanced mathematics education and offers an empirically grounded model for fostering twenty-first-century competencies in elementary mathematics classrooms.

Methods

This study adopted a Research and Development (R&D) methodology to design, develop, and evaluate a Wordwall-integrated multimodal interactive digital textbook for elementary mathematics learning. The development process was guided by the ADDIE framework Analysis, Design, Development, Implementation, and Evaluation which provides a systematic and iterative approach to instructional design. The selection of the ADDIE model was based on its capacity to align learning objectives, instructional materials, technological features, and evaluation procedures within a coherent development cycle. Furthermore, the framework facilitates continuous refinement through expert review and classroom-based implementation, ensuring that the developed product is pedagogically sound and empirically validated. To examine the effectiveness of the developed textbook, the study employed a one-group pretest–posttest design during the implementation phase. This design enabled the assessment of changes in students' collaborative skills and creative thinking following engagement with the instructional intervention (Alsadoon et al., 2022; Vrcelj et al., 2023).

Participants and Research Context

The study was conducted at SD Negeri 27 Kota Sorong, Indonesia. Participants consisted of 20 fourth-grade students enrolled in Class IV C. The class was selected purposively based on its alignment with the curricular content addressed in the intervention and the consistency of student attendance throughout the implementation period. The instructional intervention was conducted over four consecutive learning sessions focusing on area and volume measurement, topics prescribed within the Indonesian Merdeka Curriculum for elementary mathematics education.

Development of the Digital Textbook

The multimodal digital textbook was designed to integrate textual explanations, visual representations, instructional videos, interactive activities, and gamified assessments within a single learning environment (Mayer, 2021). Canva was utilized to develop the visual layout and multimedia components, while the completed materials were converted into an interactive flipbook format using Heyzine. To promote active participation and engagement, Wordwall activities were embedded throughout the textbook to provide interactive exercises, collaborative problem-solving opportunities, and immediate formative feedback (Dichev & Dicheva, 2017; Oliveira et al., 2021).

The instructional design emphasized the integration of multimodal learning experiences with structured collaborative activities. Each learning unit incorporated contextual problem

situations, guided exploration tasks, collaborative discussion prompts, practice activities, and reflective assessments intended to support both conceptual understanding and the development of twenty-first-century competencies.

Instruments

Data were collected using four complementary instruments designed to evaluate the validity, practicality, and effectiveness of the developed textbook. First, expert validation sheets were employed to assess the quality of the instructional product across three dimensions: content validity, media quality, and instructional design. Validation was conducted by six experts, comprising two mathematics content experts, two educational media experts, and two instructional design experts.

Second, practicality questionnaires were administered to both teachers and students following implementation. The questionnaires evaluated perceptions regarding usability, accessibility, interactivity, content relevance, support for collaborative learning, facilitation of creative thinking, motivational value, assessment features, and overall user satisfaction (Alsadoon et al., 2022; Ghavifekr & Rosdy, 2015). Third, students' collaborative skills were assessed using an observation rubric completed during classroom activities. The rubric measured four behavioral indicators that reflect effective collaboration: active contribution, cooperation with peers, responsibility toward group tasks, and openness to diverse perspectives during mathematical discussions (Vrcelj et al., 2023).

Fourth, creative thinking skills were measured through a pretest and posttest developed on the basis of Guilford's framework of creativity. The assessment evaluated four dimensions of creative thinking fluency, flexibility, originality, and elaboration within the context of elementary mathematics problem-solving tasks (Leikin & Pitta-Pantazi, 2013). Prior to implementation, the observation rubric and creative thinking assessment were reviewed and refined to ensure alignment with the targeted constructs and learning objectives.

Procedure

The implementation phase was conducted across four instructional sessions. Students accessed the digital textbook through links distributed via WhatsApp, allowing flexible access to the learning materials. Each lesson followed a structured instructional sequence.

The learning process began with an apperception phase designed to activate prior knowledge and connect mathematical concepts to contextual situations. Students then engaged with multimodal learning materials, including visual representations, animations, videos, and interactive content embedded within the textbook (Mayer, 2021). Subsequently, students participated in guided group discussions and collaborative problem-solving activities designed to encourage mathematical communication and collective reasoning. Practice tasks were completed collaboratively through the "Let's Practice" activities, while formative assessments were administered using Wordwall-based quizzes that provided immediate feedback on student responses (Cunha et al., 2018; Dichev & Dicheva, 2017).

Throughout the implementation process, collaborative behaviors were systematically observed and documented using the observation rubric. Creative thinking performance was measured through the administration of pretest and posttest assessments before and after the intervention.

Data Analysis

Quantitative data were analyzed using descriptive statistical techniques. Validation and practicality scores were calculated as percentage-based feasibility indices and interpreted according to established R&D evaluation criteria. Validation scores of 85% or higher were categorized as very valid, while practicality scores of 90% or higher were categorized as very practical. Students' collaborative skills were analyzed by calculating the average percentage achievement across the four observed indicators. The resulting scores were subsequently classified into predetermined performance categories to facilitate interpretation of collaborative competence.

Improvement in creative thinking was examined using the normalized gain (N-gain) index. N-gain values were interpreted according to conventional criteria: values below 0.30 were classified as low, values between 0.30 and 0.70 as moderate, and values above 0.70 as high. To provide a comprehensive evaluation of instructional effectiveness, N-gain results were interpreted alongside collaboration performance outcomes.

Success Criteria

The quality of the developed digital textbook was evaluated against three predetermined criteria. First, the textbook was considered valid if expert validation scores reached at least 85% across content, media, and instructional design dimensions. Second, the product was considered practical if both teacher and student responses achieved a minimum rating of 90%. Third, the textbook was considered effective if students demonstrated at least a moderate improvement in creative thinking (N-gain ≥ 0.30) and attained an average collaboration score of 70% or higher. The fulfillment of these criteria indicated that the Wordwall-integrated multimodal digital textbook was valid, practical, and effective in supporting the development of collaborative skills and creative thinking within elementary mathematics learning (Alsadoon et al., 2022; Cunha et al., 2018; Vrcelj et al., 2023).

Results

The findings are organized into three interrelated sections corresponding to the objectives of the study: (1) the development and validation of the Wordwall-integrated multimodal interactive digital textbook, (2) its implementation and practicality in classroom settings, and (3) its effectiveness in promoting students' collaborative skills and creative thinking in elementary mathematics learning.

Development of the Wordwall-Integrated Multimodal Interactive Digital Textbook

The development of the digital textbook followed the ADDIE instructional design framework, ensuring systematic alignment among curricular objectives, multimodal learning resources, gamified activities, and targeted twenty-first-century competencies. Each phase of the development process contributed to establishing the pedagogical and technical quality of the instructional product.

Analysis Phase

The initial analysis was conducted at SD Negeri 27 Kota Sorong and focused on the Grade IV mathematics topic of area and volume measurement. Although the Indonesian Merdeka Curriculum emphasizes student-centered and flexible learning, classroom observations and interviews with teachers revealed that instructional practices remained largely dependent on conventional printed textbooks and teacher-directed explanations. Interactive learning resources and multimodal instructional supports were rarely utilized, limiting opportunities for students to engage in collaborative problem-solving and creative mathematical exploration. These findings were further supported by a preliminary diagnostic survey involving 27 fourth-grade students. The survey indicated that many students experienced difficulties participating actively in group discussions, articulating mathematical ideas, and generating multiple solution strategies when confronted with problem-solving tasks. Collectively, these findings highlighted the need for an instructional resource capable of facilitating active engagement, collaborative interaction, and creative reasoning through digitally mediated learning experiences.

Design Phase

Based on the identified needs, an instructional design blueprint was developed to align mathematical content with indicators of collaborative and creative thinking. The textbook was designed as a multimodal learning environment integrating textual explanations, instructional videos, interactive visualizations, and gamified learning activities. Content selection and sequencing were aligned with the Grade IV mathematics curriculum issued by the Indonesian Ministry of Education, Culture, Research, and Technology and supported by supplementary instructional materials. The textbook structure consisted of user guidance, conceptual explanations, video-based demonstrations, collaborative “Let’s Practice” activities, and interactive assessments. Accessibility considerations were incorporated through distribution via a Heyzine-hosted platform that could be accessed through WhatsApp class groups, thereby facilitating communication and resource sharing between teachers and students.

Development Phase

The instructional design was subsequently translated into a functional digital product using three integrated digital platforms. Canva was utilized to develop the visual design and organize multimedia content, while Heyzine was employed to convert the materials into an interactive

flipbook format supporting embedded videos, hyperlinks, and user-friendly navigation. Wordwall activities were integrated to provide gamified learning experiences, including collaborative challenges, pattern-recognition exercises, and open-ended mathematical tasks that encouraged students to compare strategies and justify their reasoning. Prior to implementation, the prototype underwent technical testing to verify compatibility across devices and ensure the functionality of all embedded multimedia and interactive components.

Expert Validation

The completed prototype was evaluated by six independent experts consisting of two media specialists, two mathematics education experts, and two instructional design experts. Validation focused on content accuracy, instructional quality, media functionality, multimodal integration, and alignment with the targeted competencies of collaboration and creative thinking, presented in Table 1.

Table 1. Expert Validation Results of the Multimodal Interactive Digital Textbook

Validation Dimension	Mean Score	Category
Media Validation	0.95	Very Valid
Material Validation	0.90	Very Valid
Design Validation	0.92	Very Valid

Note: Scores represent mean feasibility indices across validators. Categories follow standard R&D criteria (≥0.85 = "Very Valid").

The results indicate that all validation dimensions exceeded the predetermined threshold for the "very valid" category. Media validation obtained the highest score (0.95), followed by instructional design (0.92) and content validation (0.90). These findings demonstrate that the developed textbook satisfied established standards of instructional quality and technical feasibility. Following expert review, several refinements were implemented, including repositioning user instructions to the homepage, adding navigation icons to improve accessibility, and integrating previously missing audio components. The revised version was subsequently utilized during classroom implementation.

Implementation and Practicality of the Digital Textbook

The implementation phase was conducted during the second semester of the academic year in a fourth-grade mathematics classroom at SD Negeri 27 Kota Sorong. The intervention focused on area and volume measurement and was implemented across four instructional sessions, each lasting approximately 60 minutes.

Students accessed the textbook through links distributed via a dedicated WhatsApp group. Each learning session followed a structured sequence consisting of: (1) activation of prior knowledge through contextual observation activities, (2) exploration of multimodal learning materials, (3) guided explanation of mathematical concepts, (4) collaborative problem-solving

through "Let's Practice" activities, (5) whole-class discussion and reflection, and (6) formative assessment using Wordwall-based quizzes.

The "Let's Practice" activities were specifically designed to promote the four dimensions of collaboration active contribution, cooperation, responsibility, and openness to diverse perspectives as well as the four dimensions of creative thinking fluency, flexibility, originality, and elaboration. Throughout implementation, observational records indicated that students actively participated in discussions, negotiated problem-solving strategies, and demonstrated increasing confidence in expressing and refining mathematical ideas. The integration of Wordwall-based formative assessments further reinforced conceptual understanding through immediate feedback and gamified engagement.

Implementation and Practicality of the Digital Textbook

Following the implementation phase, the practicality of the digital textbook was evaluated through questionnaires administered to the homeroom teacher and the 20 participating students. The assessment encompassed eight dimensions: interactivity, accessibility, content relevance, support for collaboration, facilitation of creative thinking, learning motivation, evaluation effectiveness, and overall satisfaction. Responses were quantified as percentage scores and interpreted using established R&D criteria (≥90% = "Very Practical"), as shown in Table 2.

Table 2. Practicality Assessment Results Based on Teacher and Student Responses

Aspect Assessed	Teacher (%)	Category	Student (%)	Category
Interactivity	100	Very Practical	93	Very Practical
Accessibility	100	Very Practical	90	Very Practical
Relevance	100	Very Practical	90	Very Practical
Collaboration	100	Very Practical	91	Very Practical
Creative Thinking	100	Very Practical	91	Very Practical
Motivation	100	Very Practical	94	Very Practical
Evaluation	100	Very Practical	84	Very Practical
Satisfaction	100	Very Practical	95	Very Practical
Average	100	**Very Practical**	**91**	**Very Practical**

Note: Scores represent mean percentage ratings. Categories follow standard R&D thresholds (≥90% = "Very Practical").

The classroom teacher assigned an overall practicality rating of 100%, indicating strong alignment between the instructional design and classroom needs. Student responses yielded an average practicality score of 91%, suggesting that the textbook was perceived as engaging, accessible, and supportive of learning. Although evaluation features received the lowest student rating (84%), this score remained within a high practicality range and did not substantially affect the overall positive perception of the textbook. Taken together, these findings indicate that the developed textbook is highly practical for classroom use and successfully integrates pedagogical rigor with user-friendly digital functionality.

Effectiveness of Learning Using the Multimodal Interactive Digital Textbook

The effectiveness of the multimodal interactive digital textbook was evaluated through two complementary measures: (1) students' collaborative skills during classroom implementation and (2) improvements in creative thinking skills as measured through a pretest–posttest design and normalized gain (N-gain) analysis. These measures were aligned with the effectiveness criteria established in the study.

Development of Students' Collaborative Skills

Students' collaborative skills were assessed during the four instructional sessions using a structured observation rubric. The rubric evaluated four indicators of collaboration: active contribution, cooperation, responsibility, and acceptance of diverse perspectives during group-based mathematical activities. The results are presented in Table 3.

Table 3. Analysis of Students' Collaborative Skills (n = 20)

Indicator	Meetings	Achievement (%)	Category
Active Contribution	1-4	69.3	High
Cooperate	1-4	70.3	High
Responsibility	1-4	70.5	High
Acceptance of Diverse Perspectives	1-4	70.0	High
Average		**70.0**	**High**

Note: Categories were determined according to the predefined performance criteria (≥ 70% = High).

As shown in Table 3, all four collaboration indicators achieved scores within the high-performance category. Achievement scores ranged from 69.3% to 70.5%, indicating relatively consistent performance across the observed dimensions. Responsibility yielded the highest score (70.5%), followed by cooperation (70.3%), acceptance of diverse perspectives (70.0%), and active contribution (69.3%). The overall collaboration score reached 70.0%, meeting the effectiveness criterion established for collaborative skill development.

Classroom observations further indicated that students actively engaged in group discussions, shared ideas during problem-solving activities, and participated in collaborative decision-making processes. During the "Let's Practice" activities, students worked together to solve measurement-related problems, compare solution strategies, and communicate their reasoning to peers. These findings suggest that the learning activities embedded within the digital textbook provided opportunities for collaborative engagement throughout the implementation period.

Improvement in Creative Thinking Skills

Students' creative thinking skills were evaluated using pretest and posttest assessments developed according to four dimensions of creativity derived from Guilford's framework: fluency (I1), flexibility (I2), originality (I3), and elaboration (I4). The distribution of student performance before and after the intervention is presented in Tables 4 and 5.

Table 4. Distribution of Pretest Creative Thinking Scores (n = 20)

Score Range	Category	Frequency	Percentage (%)
67.5 – 100	Creative	0	0
33 – < 67.5	Quite Creative	14	70
< 33	Less Creative	6	30
Total		20	100

The pretest results indicate that none of the students achieved the "creative" category prior to the intervention. Most students were classified as "quite creative" (70%), while 30% were categorized as "less creative." Following implementation of the multimodal interactive digital textbook, the distribution shifted positively. Four students (20%) reached the "creative" category, sixteen students (80%) remained within the "quite creative" category, and no students were classified as "less creative."

Table 5. Distribution of Posttest Creative Thinking Scores (n = 20)

Score Range	Category	Frequency	Percentage (%)
67.5 – 100	Creative	4	20
33 – < 67.5	Quite Creative	16	80
< 33	Less Creative	0	0
Total		20	100

To determine the magnitude of improvement, normalized gain (N-gain) analysis was conducted. The results are presented in Table 6.

Table 6. Normalized Gain Analysis of Creative Thinking Skills

Indicator	I1 (Fluency)	I2 (Flexibility)	I3 (Originality)	I4 (Elaboration)	Total N-Gain	Category
N-Gain	0.3	0.3	0.9	0.9	0.60	Moderate
Percentage (%)	28.5	28.3	90.0	85.6	58.1	Quite Effective

Note: N-gain interpretation: <0.30 = low; 0.30–0.70 = moderate; >0.70 = high. Effectiveness percentage ≥50% = quite effective.

The results indicate an overall N-gain score of 0.60, which falls within the moderate category. This value exceeded the minimum effectiveness criterion established in the study (N-gain ≥ 0.30). Differences were observed across the four dimensions of creative thinking. Fluency (I1) and flexibility (I2) each achieved an N-gain of 0.30, corresponding to the moderate category. In contrast, originality (I3) and elaboration (I4) attained substantially higher gains, with N-gain values of 0.90, which are classified as high. The effectiveness percentage analysis yielded an overall score of 58.1%, indicating that the intervention was categorized as quite effective. Among the four dimensions, originality demonstrated the highest effectiveness percentage (90.0%), followed by elaboration (85.6%), whereas fluency (28.5%) and flexibility (28.3%) showed comparatively lower percentages.

Taken together, the findings demonstrate that the implementation of the Wordwall-integrated multimodal interactive digital textbook was associated with positive outcomes in both collaborative skills and creative thinking. The collaborative skills assessment achieved the predefined performance criterion, while the creative thinking assessment demonstrated a moderate overall gain, indicating measurable improvement following participation in the learning intervention.

Discussion

The findings of this study provide evidence that a Wordwall-integrated multimodal interactive digital textbook can serve as an effective instructional resource for fostering collaborative and creative thinking skills in elementary mathematics learning. The high levels of validity, practicality, and effectiveness observed throughout the development and implementation processes suggest that the integration of multimodal representations and gamified learning activities can create learning environments that support both cognitive and social dimensions of mathematical engagement.

The high validity ratings obtained across content, media, and instructional design dimensions indicate that the developed textbook successfully aligned curricular objectives, mathematical content, and pedagogical features. This finding highlights the importance of systematic instructional design in the development of digital learning resources. By employing the ADDIE framework, the textbook was iteratively refined through expert review and evaluation, ensuring coherence between learning objectives, multimodal representations, and opportunities for student interaction. The positive validation outcomes further suggest that integrating multiple forms of representation including textual explanations, visual illustrations, videos, and interactive activities can enhance the pedagogical quality of mathematics learning materials by providing diverse pathways for accessing and constructing mathematical meaning.

The practicality findings demonstrate that both teachers and students perceived the digital textbook as highly usable and supportive of classroom learning. These results may be explained by the accessibility and interactivity afforded by the integration of Canva, Heyzine, and Wordwall within a single instructional platform. Unlike conventional textbooks that primarily emphasize the transmission of information, the developed resource encouraged students to actively engage with mathematical content through exploration, discussion, and immediate feedback. The high student ratings for interactivity, motivation, and collaborative learning support suggest that multimodal and gamified features contributed positively to students' learning experiences. Such findings are consistent with previous research indicating that technology-enhanced learning environments can increase engagement, motivation, and participation by providing learners with more dynamic and interactive opportunities to interact with mathematical ideas.

A particularly important finding concerns the development of students' collaborative skills. The results revealed that all collaboration indicators achieved scores within the high-performance category, suggesting that the instructional design successfully facilitated productive peer interaction during mathematics learning. The collaborative activities embedded

within the "Let's Practice" component required students to negotiate meanings, compare solution strategies, justify mathematical reasoning, and reach collective decisions. These processes are consistent with social constructivist perspectives, which emphasize that mathematical understanding is developed through interaction, dialogue, and shared meaning-making. Rather than functioning as passive recipients of information, students were positioned as active participants in collaborative problem-solving processes. The relatively balanced performance across indicators of active contribution, cooperation, responsibility, and openness to diverse perspectives further suggests that the learning environment supported multiple dimensions of collaborative competence.

The improvement in students' creative thinking skills provides additional evidence regarding the educational value of the developed textbook. The moderate overall N-gain score (0.60) indicates meaningful progress in creative mathematical thinking following the intervention. More importantly, the differential improvement observed across creativity dimensions offers insight into how specific instructional features may influence particular aspects of creative thinking. The substantial gains in originality and elaboration suggest that the multimodal and interactive characteristics of the textbook were particularly effective in encouraging students to generate novel ideas and develop more detailed mathematical explanations. Open-ended tasks, visual representations, and gamified challenges may have provided opportunities for students to explore alternative approaches and communicate their reasoning in greater depth.

At the same time, the comparatively lower gains in fluency and flexibility indicate that some dimensions of creativity may require more sustained instructional support. Generating multiple ideas and shifting between alternative problem-solving strategies are complex cognitive processes that often develop gradually through repeated exposure to divergent-thinking activities. Although the intervention provided opportunities for exploration and discussion, the relatively short implementation period may have limited the extent to which students could fully develop these capabilities. This finding suggests that future instructional designs may benefit from incorporating more frequent open-ended investigations, multiple-solution tasks, and reflective discussions aimed explicitly at promoting divergent mathematical thinking.

From a broader mathematics education perspective, the findings contribute to the growing body of research advocating the integration of multimodal and technology-enhanced learning environments in elementary classrooms. While previous studies have frequently examined digital textbooks or gamified learning platforms independently, the present study demonstrates the potential value of combining these approaches within a coherent instructional framework. The results suggest that digital textbooks can function not merely as repositories of content but as pedagogical scaffolds that support mathematical communication, collaborative inquiry, and creative reasoning. In this sense, the contribution of the present study extends beyond technological innovation to encompass the design of learning environments that intentionally cultivate essential twenty-first-century competencies through mathematics instruction.

Nevertheless, several limitations should be acknowledged. The study was conducted with a relatively small sample of students from a single elementary school and employed a one-group pretest–posttest design without a comparison group. Consequently, caution is required when generalizing the findings to broader educational contexts. Furthermore, the intervention was implemented over only four instructional sessions, which may not have been sufficient to capture longer-term developments in collaborative and creative thinking. Future research could employ quasi-experimental or longitudinal designs involving larger and more diverse samples to investigate the sustained effects of multimodal digital textbooks on students' mathematical learning and competency development. Additional qualitative analyses of classroom discourse and students' problem-solving processes may also provide deeper insights into the mechanisms through which multimodal and gamified learning environments support mathematical thinking.

Finally, the findings indicate that the Wordwall-integrated multimodal interactive digital textbook represents a promising instructional approach for supporting collaborative and creative thinking in elementary mathematics education. By combining multimodal representations, structured collaborative activities, and gamified learning experiences, the textbook created opportunities for students to engage actively with mathematical concepts while simultaneously developing competencies that are increasingly recognized as essential for learning and problem solving in the twenty-first century.

Conclusion

This study developed and evaluated a Wordwall-integrated multimodal interactive digital textbook designed to support the development of collaborative and creative thinking skills in elementary mathematics learning. Guided by the ADDIE instructional design framework, the developed textbook demonstrated high levels of validity, practicality, and effectiveness. Expert evaluations confirmed the quality of the product across content, media, and instructional design dimensions, while teacher and student responses indicated that the textbook was highly practical and suitable for classroom implementation. The findings further revealed that students achieved a high level of collaborative performance and demonstrated meaningful improvements in creative thinking, as reflected by a moderate overall N-gain score.

Beyond demonstrating the effectiveness of a specific instructional product, this study contributes to the growing discourse on technology-enhanced mathematics education by illustrating how multimodal representations and gamified learning activities can be purposefully integrated within a coherent pedagogical framework. The findings suggest that digital textbooks can function not only as repositories of mathematical content but also as instructional scaffolds that support collaborative interaction, mathematical communication, and creative reasoning. In this regard, the study highlights the potential of multimodal and interactive learning environments to facilitate the development of competencies that are increasingly recognized as essential for meaningful participation in contemporary mathematical learning.

The study also carries important implications for educational practice and instructional design. For teachers, the developed textbook provides a practical resource for creating more

interactive and student-centered mathematics learning experiences. For instructional designers and curriculum developers, the findings underscore the importance of aligning multimodal features and gamified activities with explicit learning objectives related to collaborative and creative thinking. Such alignment appears critical for ensuring that technological innovations contribute meaningfully to students' cognitive and social development rather than merely enhancing content delivery.

Several limitations should be acknowledged. The study involved a relatively small sample drawn from a single educational setting and employed a one-group pretest–posttest design, which limits the generalizability of the findings and precludes strong causal inferences. Furthermore, the relatively short implementation period may not have fully captured the long-term development of collaborative and creative thinking skills. Future research should therefore employ larger and more diverse samples, incorporate comparison groups through quasi-experimental or experimental designs, and examine the sustained impact of multimodal digital textbooks over extended periods of implementation. Further investigation is also warranted to explore adaptive digital features and their potential to support dimensions of creative thinking that demonstrated comparatively lower levels of improvement, particularly fluency and flexibility.

References

Afrila, D., & Yarmayani, A. (2018). Pengembangan media pembelajaran modul interaktif dengan software adobe flash pada mata kuliah matematika ekonomi di Universitas Batanghari Jambi. *Jurnal Ilmiah Universitas Batanghari Jambi*, *18*(3), 539-551. https://doi.org/10.33087/jiubj.v18i3.521

Alsadoon, E., Alkhawajah, A., & Suhaim, A. (2022). Effects of a gamified learning environment on students' achievement, motivations, and satisfaction. *Heliyon*, 8(8), e10249. https://doi.org/10.1016/j.heliyon.2022.e10249

Cunha, G. C. A., Barraqui, L. P., & Freitas, S. A. A. D. (2018). Evaluating the use of gamification in mathematics learning in primary school children. In *2018 IEEE Frontiers in Education Conference (FIE)* (pp. 1–5). IEEE. https://doi.org/10.1109/FIE.2018.8658950

Dichev, C., & Dicheva, D. (2017). Gamifying education: What is known, what is believed and what remains uncertain. *International Journal of Educational Technology in Higher Education, 14*(1), 1–36. https://doi.org/10.1186/s41239-017-0042-5

Ghavifekr, S., & Rosdy, W. A. W. (2015). Teaching and learning with technology: Effectiveness of ICT integration in schools. *International Journal of Research in Education and Science*, *1*(2), 175–191. https://doi.org/10.21890/ijres.23596

Ghavifekr, S., & Rosdy, W. A. W. (2015). Teaching and learning with technology: Effectiveness of ICT integration in schools. *International Journal of Research in Education and Science, 1*(2), 175–191. https://doi.org/10.21890/ijres.23596

Hanum, N. S. (2013). Keefetifan e-learning sebagai media pembelajaran (studi evaluasi model pembelajaran e-learning SMK Telkom Sandhy Putra Purwokerto). *Jurnal Pendidikan Vokasi*, *3*(1), 90-102. https://doi.org/10.21831/jpv.v3i1.1584

Haruna, N. H., & Masri, S. (2024). Development of interactive digital teaching materials based on problem based learning cultural diversity materials in social sciences learning. *Cokroaminoto Journal of Primary Education*, *7*(1), 84–95. https://doi.org/10.30605/cjpe.712024.3588

Imansari, N., & Sunaryantiningsih, I. (2017). The effect of using interactive e-modules on student learning outcomes on occupational health and safety materials. *Scientific Journal of Electrical Engineering Education*, *2*(1), 11-16. https://doi.org/10.30870/volt.v2i1.1478

Leikin, R., & Pitta-Pantazi, D. (2013). Creativity and mathematics education: The state of the art. *ZDM Mathematics Education*, *45*(2), 159–166. https://doi.org/10.1007/s11858-012-0459-1

Mawaddah, R., Triwoelandari, R., & Irfani, F. (2022). Kelayakan LKS pembelajaran IPA berbasis STEAM untuk meningkatkan keterampilan kolaborasi Siswa SD/MI. *Jurnal Cakrawala Pendas*, *8*(1), 1–14. Retrieved from https://www.ejournal.unma.ac.id/index.php/cp/article/view/1911/1204

Mayer, R. E. (2021). *Multimedia learning (3rd ed.)*. Cambridge University Press. https://doi.org/10.1017/9781316941355

Oliveira, W., Toda, A. M., Palomino, P. T., Rodrigues, L., Shi, L., Bittencourt, I., Isotani, S., Cristea, A. I., & Gasparini, I. (2021). Gamification in education: A systematic mapping study. *Educational Technology & Society*, *24*(1), 13–32. Retrieved from http://www.jstor.org/stable/jeductechsoci.18.3.75

Sadiman, A. S., Rahardjo, R., Haryono, A., & Zain, A. (2012). *Educational media: Definition, development, and utilization*. Jakarta: Rajawali Pers.

Setyo, A. A., Pomalato, S. W., Hulukati, E. P., Machmud, T., & Djafri, N. (2023). Effectiveness of TPACK-Based multimodal digital teaching materials for mathematical critical thinking ability. *International Journal of Information and Education Technology*, *13*(10), 1604-1608. https://doi.org/10.18178/ijiet.2023.13.10.1968

Suleman, N., Lukum, A., Pikoli, M., La Kilo, A., . M., Nusantasri, E., … Latjompoh, M. (2025). Validity of the 5C learning model (Connecting, Confrontation, Collaboration, Clarification, Confirmation) based on virtual laboratory to enhance students' relational. *Galore International Journal of Applied Sciences and Humanities*, *9*(3), 58–64. https://doi.org/10.52403/gijash.20250307

Voogt, J., & Roblin, N. P. (2012). A comparative analysis of international frameworks for 21st century competences: Implications for national curriculum policies. *Journal of Curriculum Studies*, *44*(3), 299–321. https://doi.org/10.1080/00220272.2012.668938

Vrcelj, Z., Hoić-Božić, N., & Holenko Dlab, M. (2023). Gamification in primary education: Effects on student motivation and collaboration. In *Proceedings of the International Conference on e-Learning and Games* (pp. 112–121). Springer.

Zubaidah, S. (2016). 21st century skills: Skills taught through learning. In *National Education Seminar* (Vol. 2, No. 2, pp. 1-17).