



Effectiveness of contextualized digital worksheets (e-lkpd) using liveworksheets to enhance mathematical critical thinking and self-regulated learning

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Article Info

Article history:

Received: Feb 28, 2026

Revised: April 15, 2026

Accepted: May 03, 2026

Keywords:

Contextualized E-LKPD;
Liveworksheets; Mathematical
Critical Thinking; Self-
Regulated Learning;
Mathematics Education.

Abstract

Background: The integration of digital technology in mathematics education is essential for fostering 21st-century skills, particularly mathematical critical thinking and self-regulated learning. However, conventional teaching practices still dominate classrooms, limiting students' active engagement and independent learning. The use of contextualized Electronic Student Worksheets (E-LKPD) integrated with Liveworksheets and real-life contexts such as online shopping offers a promising approach to create meaningful and student-centered learning experiences.

Aims: This study aims to develop a valid and practical contextualized E-LKPD using Liveworksheets and to examine its effectiveness in enhancing students' mathematical critical thinking skills and self-regulated learning.

Method: This study employed a Research and Development (R&D) approach using the ADDIE model. Participants were eighth-grade students at SMP Negeri 2 Cikarang Pusat, divided into experimental and control groups. Data were collected through validation sheets, questionnaires, tests, observations, and interviews. Data analysis used a mixed-method approach, including descriptive qualitative analysis and quantitative analysis through normality, homogeneity, and independent samples t-tests.

Results: The results indicate that the developed E-LKPD is valid and practical. Statistical analysis showed no significant difference in students' mathematical critical thinking skills between the experimental and control groups ($p = 0.412$), although the experimental group demonstrated slightly higher mean scores. In contrast, a significant improvement was found in self-regulated learning ($p < 0.001$), with higher mean scores in the experimental group.


Conclusion: The contextualized E-LKPD effectively enhances students' self-regulated learning but shows limited impact on mathematical critical thinking. Further optimization in instructional design, implementation duration, and pedagogical integration is required to improve higher-order thinking outcomes.

To cite this article: Helmy, W. W., & Jaelani, A. (2026). Effectiveness of contextualized digital worksheets (e-lkpd) using liveworksheets to enhance mathematical critical thinking and self-regulated learning. *Journal of Advanced Sciences and Mathematics Education*, 6(2), 134-151.

INTRODUCTION

The advancement of information and communication technology has brought significant transformation in the field of education, particularly in supporting 21st-century learning. Modern education emphasizes the development of critical thinking, creativity, communication, and collaboration skills (Thornhill-Miller et al., 2023). In the context of mathematics education, these competencies are essential for enabling students to solve complex problems and make reasoned decisions (Basid et al., 2024; Szabo et al., 2020). The integration of technology in the classroom allows teachers to design more innovative and engaging learning experiences (Bento Silva et al., 2020; Boonmoh et al., 2021; Goh & Sigala, 2020; Yurtseven Avci et al., 2020; Zou et al., 2025). Digital

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learning tools can support students in understanding mathematical concepts through interactive and visual approaches (Cirneanu & Moldoveanu, 2024). Such integration also encourages students to participate actively in the learning process rather than passively receiving information. Technology-based learning environments provide flexibility and accessibility that enhance students' learning opportunities (Afonso et al., 2025; Huda, 2023; Sitthiworachart et al., 2022). Furthermore, these environments facilitate personalized learning that can accommodate different learning styles and abilities. As a result, the use of digital technology has become increasingly important in improving the quality of mathematics education. Therefore, integrating technology into learning is no longer optional but a necessity in modern educational practices.

However, despite the rapid development of educational technology, many schools still rely on conventional teaching methods. Traditional instruction often focuses on teacher-centered approaches that emphasize procedural knowledge rather than conceptual understanding (Woods & Copur-Gencturk, 2024; Zvoch et al., 2021). This approach limits students' opportunities to develop higher-order thinking skills, particularly critical thinking. In many cases, students are trained to follow fixed procedures instead of exploring alternative problem-solving strategies (Fülöp, 2021; Gvozdic & Sander, 2020; Ninomiya et al., 2024). As a consequence, students' ability to analyze, evaluate, and synthesize information remains underdeveloped. In addition, conventional learning environments often do not encourage students to take responsibility for their own learning (Müller & Mildenerger, 2021; Sasson & Yehuda, 2023; Valtonen et al., 2021). This condition hinders the development of self-regulated learning, which is essential for independent and lifelong learning. Students tend to depend heavily on teachers for guidance and direction in completing tasks. The lack of autonomy reduces students' motivation and engagement in learning activities. Therefore, there is a need for innovative instructional approaches that promote active and independent learning.

One of the potential solutions to address these challenges is the development of interactive digital learning media. Electronic Student Worksheets (E-LKPD) represent a form of digital innovation that can transform conventional worksheets into more engaging learning tools. Through integration with platforms such as Liveworksheets, E-LKPD can provide interactive features such as instant feedback and automated responses. These features enable students to monitor their own learning progress more effectively. In addition, the use of real-life contexts, such as online shopping scenarios, can make mathematics learning more meaningful and relevant (Dolapcioglu & Doğanay, 2022; T. Tran et al., 2020). Contextual learning helps students connect abstract mathematical concepts with everyday experiences. This approach encourages students to think critically when analyzing information and making decisions. Furthermore, interactive digital worksheets can support the development of self-regulated learning by promoting independence and responsibility. Students are given opportunities to manage their own learning processes through structured activities. However, although these approaches are promising, their combined impact on both critical thinking and self-regulated learning has not been fully explored.

A growing body of literature has emphasized the importance of critical thinking in mathematics education, with studies focusing on its conceptualization, measurement, and enhancement through subject-based instructional approaches (Arisoy & Aybek, 2021; Monteleone et al., 2023; Sachdeva & Eggen, 2021). These studies highlight the cognitive dimension of learning, particularly in developing students' analytical and reasoning skills; however, they predominantly examine critical thinking in isolation without integrating digital learning environments or interactive technological media. At the same time, extensive research on self-regulated learning has demonstrated its significant role in improving students' academic performance, motivation, and learning autonomy, particularly within online and technology-supported environments (Carter Jr et al., 2020; Jin et al., 2023; Palalas & Wark, 2020; Theobald, 2021; Wolters & Brady, 2021). Despite this, these studies tend to focus on metacognitive and motivational aspects separately from cognitive

outcomes such as critical thinking, resulting in a fragmented understanding of learning processes. Furthermore, research in mathematics education has also highlighted the importance of contextual and real-life learning approaches, including mathematical modeling and problem-based learning, in enhancing conceptual understanding and engagement (Abassian et al., 2020; Verschaffel et al., 2020). However, the integration of contextual learning with interactive digital tools remains limited, particularly in the form of structured digital worksheets that facilitate both cognitive and metacognitive development simultaneously. Therefore, it can be identified that previous studies largely examine critical thinking, self-regulated learning, and technology integration as separate constructs, with limited empirical evidence investigating their combined effects within a single instructional framework; thus, this study addresses this gap by developing and evaluating a contextualized E-LKPD using Liveworksheets to examine its dual impact on students' mathematical critical thinking and self-regulated learning.

This study aims to develop a contextualized Electronic Student Worksheet (E-LKPD) integrated with the Liveworksheets platform that meets the criteria of validity and practicality in mathematics learning. The study seeks to evaluate the quality of the developed learning media in supporting effective classroom implementation. In addition, it aims to investigate the influence of E-LKPD on students' critical thinking skills in mathematics learning. The study also examines the impact of E-LKPD on students' self-regulated learning abilities. By integrating real-life contexts into digital worksheets, the study attempts to create meaningful learning experiences for students. The research further explores how interactive media can support active student engagement. It also analyzes whether the use of E-LKPD can promote independent learning behaviors among students. The findings are expected to provide insights into the effectiveness of digital learning tools in enhancing learning outcomes. Moreover, the study aims to contribute to the development of innovative instructional strategies in mathematics education. Ultimately, this research seeks to support the improvement of learning quality through the integration of technology and contextual learning approaches.

LITERATURE REVIEW

The integration of digital technology in mathematics education has become an essential component in enhancing students' learning experiences in the 21st century. Technology provides opportunities for more interactive, flexible, and student-centered learning environments that support deeper conceptual understanding (Bhardwaj et al., 2025; Kerimbayev et al., 2023; Swai, 2025). Digital learning tools, such as electronic worksheets, allow students to engage with mathematical content in more dynamic ways (Cirneanu & Moldoveanu, 2024; Dyrvold & Bergvall, 2023; Galanti et al., 2020; Weinhandl et al., 2021). These tools facilitate immediate feedback, which helps students identify and correct their mistakes in real time. As a result, students are encouraged to take a more active role in their own learning processes. The use of digital platforms also enables teachers to design learning activities that are more varied and engaging (Gameil & Al-Abdullatif, 2023; Hase & Kuhl, 2024; Kiryakova, 2022; Meier, 2021). Furthermore, technology-enhanced learning environments can accommodate diverse learning styles and individual learning needs (Achtypi et al., 2026; Downie et al., 2021; Smith et al., 2021). The integration of digital tools in mathematics education is closely associated with the development of higher-order thinking skills. Students are provided with opportunities to explore, analyze, and evaluate mathematical concepts more effectively. Therefore, digital technology plays a crucial role in transforming traditional mathematics instruction into more innovative and meaningful learning experiences.

Electronic Student Worksheets (E-LKPD) have emerged as one of the most widely used forms of digital learning media in recent years. E-LKPD represents a transformation of conventional

worksheets into interactive digital formats that can be accessed through various devices. These worksheets are designed to guide students through structured learning activities while promoting active engagement. The integration of platforms such as Liveworksheets enhances the functionality of E-LKPD by providing interactive features, including automatic scoring and instant feedback. These features enable students to monitor their learning progress independently. In addition, Liveworksheets allows for the inclusion of multimedia elements such as images, audio, and videos, which can enrich the learning experience. The use of E-LKPD also supports flexible learning, as students can access materials anytime and anywhere. This flexibility is particularly important in supporting independent learning behaviors. Furthermore, the interactive nature of E-LKPD encourages students to participate more actively in completing tasks. Therefore, E-LKPD integrated with Liveworksheets offers a promising approach for improving the effectiveness of mathematics learning.

Critical thinking is widely recognized as a fundamental cognitive skill in mathematics education. It involves the ability to analyze information, evaluate arguments, and make logical decisions based on evidence. In mathematics learning, critical thinking enables students to understand concepts deeply rather than simply memorizing procedures (Dolapcioglu & Doğanay, 2022; Mahmud et al., 2021; Sachdeva & Eggen, 2021; Setiana et al., 2021). Students with strong critical thinking skills are better able to solve complex and non-routine problems (Evans et al., 2021; Kablan & Günen, 2021). They can also apply mathematical knowledge in various contexts and situations. The development of critical thinking requires learning environments that encourage inquiry, exploration, and reflection (Indrašienė et al., 2023; Lu, 2021; Wale & Bishaw, 2020). Interactive learning media can support these processes by providing opportunities for students to engage in meaningful problem-solving activities (Daryanes et al., 2023; Hsbollah & Hassan, 2022; Koehler & Vilarinho-Pereira, 2023). However, developing critical thinking skills is a complex process that requires consistent practice and appropriate instructional strategies. Simply introducing digital tools may not be sufficient to significantly improve these skills. Therefore, it is important to design learning activities that specifically target critical thinking development within digital environments.

In addition to cognitive skills, self-regulated learning plays a critical role in students' academic success. Self-regulated learning refers to the ability of students to plan, monitor, and evaluate their own learning processes (Arianto & Hanif, 2024; Chou & Zou, 2020; Hachem et al., 2022; Vosniadou, 2020). Students who possess strong self-regulated learning skills tend to be more independent and responsible for their learning outcomes (Babayigit & Guven, 2020; Zheng & Zhang, 2020). They are capable of setting goals, managing time, and selecting appropriate learning strategies. In technology-enhanced learning environments, self-regulated learning becomes even more important due to the increased autonomy given to students. Digital learning tools, such as E-LKPD, can support self-regulated learning by providing structured tasks and feedback mechanisms. These features help students track their progress and adjust their learning strategies accordingly. Furthermore, interactive platforms encourage students to take initiative in completing learning activities. The flexibility of digital learning environments also allows students to learn at their own pace. Therefore, integrating self-regulated learning into digital learning design is essential for maximizing student outcomes.

The use of contextual learning approaches has been widely recognized as an effective strategy for enhancing students' understanding of mathematical concepts. Contextual learning involves presenting mathematical problems in real-life situations that are relevant to students' experiences. This approach helps students connect abstract concepts with practical applications. One example of contextual learning is the use of online shopping scenarios to illustrate mathematical concepts such as percentages, discounts, and budgeting. Such contexts make learning more meaningful and engaging for students. In addition, contextual learning can stimulate students' critical thinking by

requiring them to analyze real-world problems. It also encourages students to make decisions based on logical reasoning. When combined with digital learning tools, contextual learning can provide a powerful learning experience. However, the integration of contextual approaches with interactive digital worksheets remains limited. Furthermore, few studies have explored the combined impact of contextualized digital worksheets on both critical thinking and self-regulated learning. Therefore, this study seeks to address this gap by investigating the effectiveness of contextualized E-LKPD using Liveworksheets in enhancing both cognitive and metacognitive learning outcomes in mathematics education.

METHOD

Research Design

This study employed a Research and Development (R&D) approach using the ADDIE model, which consists of five systematic stages: Analysis, Design, Development, Implementation, and Evaluation. The selection of the ADDIE model was based on its structured and iterative nature, which enables continuous refinement of educational products. In the analysis stage, the researcher identified learning needs, student characteristics, curriculum requirements, and the relevance of integrating real-life contexts into mathematics learning. The design stage involved planning the structure, content, and interface of the E-LKPD integrated with the Liveworksheets platform. In the development stage, the E-LKPD was produced and validated by experts to ensure content accuracy, media quality, and linguistic clarity. The implementation stage included both limited and large-scale trials to evaluate the practicality and effectiveness of the developed product. The evaluation stage was conducted to assess the overall quality of the E-LKPD and to perform necessary revisions. In addition, a quasi-experimental design was applied during the implementation phase. The study compared an experimental group that used the developed E-LKPD with a control group that received conventional instruction. This design allowed the researcher to examine the impact of the intervention on students' critical thinking and self-regulated learning.

Participant

The participants of this study were eighth-grade students from SMP Negeri 2 Cikarang Pusat in the academic year 2025/2026. The study was conducted through two stages, namely limited trials and large-scale trials. In the limited trial stage, approximately 12 to 15 students were involved to assess the readability, usability, and initial practicality of the developed E-LKPD. Feedback obtained from this stage was used to revise and improve the product before wider implementation. In the large-scale trial stage, two classes were selected, each consisting of approximately 30 to 34 students. One class was assigned as the experimental group, while the other served as the control group. The population of this study included all eighth-grade students at the school. The sampling technique used was purposive sampling for the limited trial and cluster random sampling for the large-scale trial. The selection of participants was based on similar academic characteristics to ensure comparability between groups. This approach aimed to minimize bias and ensure the validity of the findings. The participants were considered representative of junior high school students in mathematics learning contexts.

Instrument

This study utilized multiple instruments to ensure comprehensive data collection. First, expert validation sheets were used to assess the validity of the E-LKPD, covering aspects of content, media design, and language clarity. Second, questionnaires using a Likert scale were administered to both students and teachers to evaluate the practicality and usability of the developed product. Third, a critical thinking test consisting of three essay questions was used to measure students' mathematical critical thinking skills. These questions were developed based on indicators such as interpretation,

analysis, evaluation, and inference. Fourth, a self-regulated learning questionnaire consisting of 25 items was used to assess students' learning independence. In addition, observation sheets were used to record students' learning activities during the implementation process. Interviews were conducted to obtain in-depth information regarding students' and teachers' experiences using the E-LKPD. Data collection was carried out during both limited and large-scale trials. All instruments were designed to support the validity and reliability of the research data. The combination of quantitative and qualitative instruments allowed for a more comprehensive evaluation of the developed product.

Data Analysis

The data analysis in this study employed a mixed-method approach that combined qualitative and quantitative techniques. Qualitative data obtained from expert validation, observations, and interviews were analyzed descriptively to evaluate the validity and practicality of the E-LKPD. Quantitative data from tests and questionnaires were analyzed using statistical methods. Prior to hypothesis testing, prerequisite tests were conducted, including normality and homogeneity tests. The normality test was used to determine whether the data were normally distributed. The homogeneity test was conducted to examine the equality of variance between groups. After fulfilling these assumptions, an independent samples t-test was applied to compare the mean scores of the experimental and control groups. This test was used to determine the effectiveness of the E-LKPD in improving students' critical thinking and self-regulated learning. Descriptive statistics were also used to present mean scores and standard deviations. The results of the analysis were interpreted to draw conclusions regarding the impact of the developed learning media. This approach ensured that both numerical trends and contextual insights were captured in the analysis.

Procedure

The research procedure followed the five stages of the ADDIE model in a systematic manner. In the analysis stage, the researcher identified learning problems, student needs, curriculum demands, and the relevance of using online shopping contexts in mathematics learning. In the design stage, the structure of the E-LKPD was planned, including learning objectives, content organization, interactive features, and assessment instruments. In the development stage, the E-LKPD was created and integrated with the Liveworksheets platform, followed by expert validation and revision based on feedback. In the implementation stage, the developed product was tested through limited and large-scale trials. The experimental group used the E-LKPD, while the control group received conventional instruction. Data were collected during this stage through tests, questionnaires, observations, and interviews. In the evaluation stage, all collected data were analyzed to determine the validity, practicality, and effectiveness of the E-LKPD. The findings were used to revise and improve the final product. The study was conducted over one academic semester, from September to December 2025. This systematic procedure ensured that the developed E-LKPD met the expected standards and research objectives.

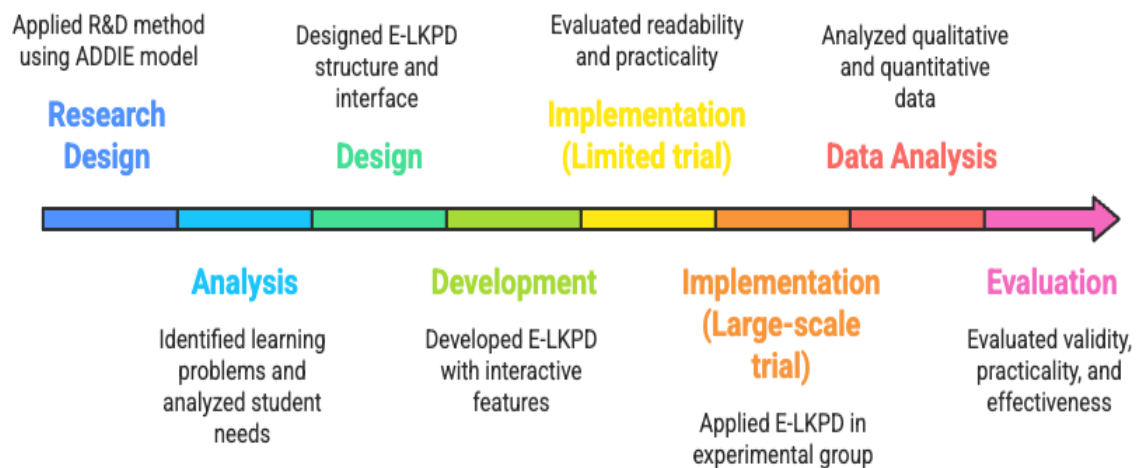


Figure 1. Research framework for improving students' numeracy literacy

RESULTS AND DISCUSSION

Results

The results of this study are presented based on two main outcome variables, namely students' mathematical critical thinking skills and self-regulated learning. Before conducting hypothesis testing, the data were examined through normality and homogeneity tests to determine whether parametric statistical analysis could be applied. The normality test was conducted using the Kolmogorov–Smirnov and Shapiro–Wilk tests, while the homogeneity test was examined using Levene's Test of Equality of Variances. After the assumptions were fulfilled, an independent samples t-test was used to compare the mean scores between the experimental class and the control class. The experimental class received learning treatment using contextualized E-LKPD integrated with Liveworksheets, while the control class received conventional instruction. The results are described in detail in the following sections.

Mathematical Critical Thinking Skills

The analysis of students' mathematical critical thinking skills began with the normality test. The results showed that the significance values for the experimental class were 0.100 in the Kolmogorov–Smirnov test and 0.060 in the Shapiro–Wilk test. Meanwhile, the control class obtained significance values of 0.181 in the Kolmogorov–Smirnov test and 0.209 in the Shapiro–Wilk test. Since all significance values were greater than 0.05, the data from both classes were normally distributed. This result indicates that the critical thinking score data fulfilled the normality assumption required for parametric analysis.

Table 1. Normality test results for mathematical critical thinking skills

Group	Kolmogorov–Smirnov Sig.	Shapiro–Wilk Sig.	Interpretation
Experimental Class	0.100	0.060	Normal
Control Class	0.181	0.209	Normal

The homogeneity test was then conducted to examine whether the variance between the experimental and control classes was equal. Based on Levene's Test, the significance value was 0.989. Since this value was higher than 0.05, the variance of the two groups was homogeneous. Therefore, the assumption of homogeneity was fulfilled, and the independent samples t-test could be conducted using the equal variances assumed output.

Table 2. Homogeneity test results for mathematical critical thinking skills

Variable	Levene Statistic	df1	df2	Sig.	Interpretation
Final Score	0.000	1	66	0.989	Homogeneous

The independent samples t-test was used to determine whether there was a significant difference in mathematical critical thinking skills between the two classes. The result showed that the significance value was 0.412, which was greater than 0.05. This finding indicates that there was no statistically significant difference between students who learned using contextualized E-LKPD integrated with Liveworksheets and those who learned through conventional instruction. Although the mean score of the experimental class was slightly higher than that of the control class, the difference was not strong enough to be considered statistically significant. The experimental class obtained a mean score of 85.82, while the control class obtained a mean score of 85.47. The mean difference was only 0.353, indicating a very small difference between the two groups.

Table 3. Independent samples t-test results for mathematical critical thinking skills

Group	N	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Interpretation
Experimental Class	34	85.82	1.817	-0.825	66	0.412	Not significant
Control Class	34	85.47	1.710				

These results suggest that the use of contextualized E-LKPD integrated with Liveworksheets did not produce a statistically significant improvement in students' mathematical critical thinking skills compared with conventional learning. Nevertheless, the slightly higher mean score in the experimental class indicates a positive tendency that may require longer implementation, more complex problem-solving tasks, or stronger instructional scaffolding to produce a measurable effect. Therefore, the findings should be interpreted carefully: the intervention showed potential, but its effect on mathematical critical thinking was limited in this study.

Self-Regulated Learning

The second outcome analyzed in this study was students' self-regulated learning. The normality test showed that the experimental class obtained significance values of 0.200 in the Kolmogorov–Smirnov test and 0.346 in the Shapiro–Wilk test. Meanwhile, the control class obtained a significance value of 0.048 in the Kolmogorov–Smirnov test and 0.081 in the Shapiro–Wilk test. Although the Kolmogorov–Smirnov value for the control class was below 0.05, the Shapiro–Wilk value was greater than 0.05. Considering the sample size of each group and the relevance of the Shapiro–Wilk test for relatively small samples, the data were interpreted as meeting the normality assumption. Thus, the self-regulated learning data were considered appropriate for further parametric testing.

Table 4. Normality test results for self-regulated learning

Group	Kolmogorov–Smirnov Sig.	Shapiro–Wilk Sig.	Interpretation
Experimental Class	0.200	0.346	Normal
Control Class	0.048	0.081	Normal based on Shapiro–Wilk

The homogeneity test showed that the significance value based on mean was 0.718. This value was greater than 0.05, indicating that the variance between the experimental and control classes was homogeneous. The assumption of equal variance was therefore fulfilled. This result allowed the use of the independent samples t-test to examine differences in self-regulated learning between the two groups.

Table 5. Homogeneity test results for self-regulated learning

Variable	Levene Statistic	df1	df2	Sig.
Questionnaire Score	0.132	1	66	0.718

The independent samples t-test showed a significance value of 0.000, which was lower than 0.05. This result indicates that there was a statistically significant difference in self-regulated learning between the experimental and control classes. The experimental class obtained a mean score of 101.44, while the control class obtained a mean score of 92.12. The mean difference of 9.324 points indicates that students who used contextualized E-LKPD integrated with Liveworksheets demonstrated higher self-regulated learning than those who received conventional instruction. This finding suggests that the interactive features, structured activities, and contextual learning tasks provided in the E-LKPD supported students in managing their own learning processes more effectively.

Table 6. Independent samples t-test results for self-regulated learning

Group	N	Mean	Std. Deviation	t	df	Sig. (2-tailed)	Interpretation
Experimental Class	34	101.44	9.721	-3.804	66	0.000	Significant
Control Class	34	92.12	10.479				

The higher score in the experimental class indicates that students became more independent in following learning activities, completing tasks, and monitoring their progress. The Liveworksheets-based E-LKPD provided students with interactive learning experiences that allowed them to receive immediate responses and work through activities more autonomously. The online shopping context also made the learning tasks more familiar and relevant to students' daily experiences. This relevance may have increased students' willingness to engage with the material and take responsibility for completing the learning activities. Therefore, the results support the conclusion that contextualized E-LKPD has a stronger effect on students' self-regulated learning than on mathematical critical thinking skills.

Overall, the findings indicate that the developed contextualized E-LKPD integrated with Liveworksheets produced different effects on the two measured learning outcomes. For mathematical critical thinking skills, the difference between the experimental and control classes was not statistically significant. However, for self-regulated learning, the experimental class showed significantly higher results than the control class. These findings suggest that the intervention was more effective in supporting students' metacognitive and independent learning behaviors than in producing immediate measurable gains in critical thinking skills. The summary of the results is presented in Table 7.

Table 7. Summary of statistical findings

Learning Outcome	Experimental Mean	Control Mean	Sig. Value	Statistical Decision	Interpretation
Mathematical Critical Thinking	85.82	85.47	0.412	H_0 accepted	Not significant
Self-Regulated Learning	101.44	92.12	0.000	H_0 rejected	Significant

The results demonstrate that contextualized E-LKPD using Liveworksheets has a differentiated impact on students' learning outcomes. Its contribution to self-regulated learning is statistically supported, while its contribution to mathematical critical thinking remains limited. This pattern indicates that interactive digital worksheets may more directly support learning autonomy, task completion, and self-monitoring than the deeper cognitive processes involved in mathematical critical thinking. Therefore, future implementation should consider adding more complex problem-

solving activities, guided inquiry tasks, reflective prompts, and longer intervention periods to strengthen the impact on students' critical thinking skills.

Discussion

The findings of this study reveal that the implementation of contextualized E-LKPD using Liveworksheets produced varied outcomes across different learning domains. Although the intervention was designed to enhance students' mathematical critical thinking skills, the improvement observed was not statistically significant. This result suggests that the use of digital learning media alone is not sufficient to produce measurable gains in higher-order cognitive skills. Previous studies have reported similar findings, indicating that the effectiveness of digital tools depends heavily on instructional design and implementation quality (Ahmad et al., 2022; Chugh et al., 2023; Gameil & Al-Abdullatif, 2023; Konstantinidou & Nisiforou, 2022; Müller et al., 2023; Spatioti et al., 2023). The lack of statistical significance may be attributed to factors such as limited intervention duration, insufficient cognitive challenge, and relatively similar baseline abilities between groups. In line with earlier research, short-term exposure to digital learning tools often results in incremental rather than substantial cognitive improvements. Some studies have emphasized that critical thinking development requires sustained engagement with complex and non-routine problems. In the present study, the tasks provided through the E-LKPD may not have fully challenged students' analytical and evaluative abilities. Additionally, the contextual approach used may have been more effective in promoting engagement than deep cognitive processing. Therefore, the findings indicate that the relationship between digital learning tools and critical thinking is influenced by multiple instructional and contextual factors.

In contrast, the results show a statistically significant improvement in students' self-regulated learning in the experimental group compared to the control group. This finding supports the growing body of literature suggesting that technology-enhanced learning environments are particularly effective in promoting metacognitive skills (Sui et al., 2024; T. M. Tran & Hasegawa, 2022; Urbina et al., 2021). The interactive features of Liveworksheets, such as immediate feedback and structured task progression, provide opportunities for students to monitor and regulate their own learning processes. Previous studies have consistently shown that self-regulated learning is more responsive to digital interventions than cognitive outcomes such as critical thinking (Anthonysamy et al., 2021; Chang et al., 2022; Edisherashvili et al., 2022; Guo, 2022; Ritz et al., 2023; Xu et al., 2023). The flexibility offered by digital platforms allows students to engage with learning materials at their own pace, which is a key aspect of autonomous learning. In addition, the structured nature of E-LKPD encourages students to plan, execute, and evaluate their learning activities systematically. These findings are consistent with research indicating that digital worksheets can enhance students' responsibility and discipline in completing tasks. Furthermore, the use of interactive media has been associated with increased student motivation and engagement [need citation]. The higher level of engagement observed in the experimental group may explain the significant improvement in self-regulated learning. Therefore, the results confirm that contextualized E-LKPD is particularly effective in fostering independent learning behaviors.

The integration of real-life contexts, such as online shopping scenarios, also plays an important role in shaping students' learning experiences. Contextual learning has been widely recognized as a strategy that enhances the relevance and meaningfulness of mathematical concepts (Basid et al., 2024; Koskinen & Pitkäniemi, 2022). By connecting abstract concepts with everyday situations, students are more likely to engage actively in learning activities. Previous studies have demonstrated that contextual problems can increase students' motivation and participation in mathematics learning. In this study, the use of familiar contexts may have contributed to students' increased interest and involvement. However, the effect of contextual learning on critical thinking appears to

be less direct. Some research suggests that contextual learning can improve critical thinking when combined with inquiry-based or problem-based approaches. In the present study, the contextual tasks may not have been sufficiently complex to stimulate deep analytical thinking. This indicates that the level of cognitive demand embedded in contextual problems is a crucial factor. Additionally, students may require explicit guidance and scaffolding to develop higher-order thinking skills within contextual environments. Therefore, the findings highlight the need for more structured and cognitively demanding tasks in contextual digital learning.

Another factor that may have influenced the results is the duration of the intervention and the overall learning conditions. The study was conducted within a relatively short timeframe, which may not have been sufficient to observe significant improvements in critical thinking. Previous longitudinal studies have shown that the development of higher-order thinking skills requires sustained practice over time (Liu et al., 2022). In contrast, self-regulated learning can be developed more rapidly through structured and repetitive learning activities. The limited duration of the intervention may explain why significant effects were observed only in self-regulated learning. In addition, students' prior experience with digital tools may have influenced their ability to adapt to the E-LKPD platform. Students who are unfamiliar with technology may require additional time to become comfortable with digital learning environments. The role of the teacher as a facilitator is also critical in maximizing the effectiveness of the intervention. Without adequate guidance, students may not fully utilize the interactive features provided by the platform. Furthermore, differences in student motivation and engagement levels may have contributed to the variation in outcomes. Therefore, the effectiveness of digital learning tools is influenced by both internal and external factors within the learning environment.

Overall, the findings of this study emphasize the importance of integrating digital media with appropriate pedagogical strategies to achieve optimal learning outcomes. The results suggest that while contextualized E-LKPD is effective in enhancing self-regulated learning, its impact on critical thinking remains limited without additional instructional support. Previous research has indicated that combining digital tools with approaches such as problem-based learning or inquiry-based learning can significantly improve critical thinking skills. Therefore, future implementations should consider integrating E-LKPD with more cognitively demanding learning models. In addition, the design of learning tasks should include higher-order thinking components that encourage analysis, evaluation, and reflection. Extending the duration of the intervention may also provide students with more opportunities to develop critical thinking skills. Furthermore, incorporating reflective activities and feedback mechanisms could strengthen students' cognitive engagement. The findings also highlight the need for teacher training to ensure effective use of digital learning media. Teachers play a crucial role in guiding students and providing scaffolding during the learning process. Therefore, the success of digital learning interventions depends on the synergy between media design, pedagogical strategies, and teacher facilitation.

Implications

The findings of this study provide several important implications for the development of mathematics learning in technology-enhanced environments. First, the significant improvement in students' self-regulated learning indicates that contextualized E-LKPD integrated with Liveworksheets can serve as an effective tool to foster independent learning behaviors. This suggests that digital learning media should be designed not only to deliver content but also to support students' ability to manage their own learning processes. Second, the limited impact on mathematical critical thinking highlights the need for more carefully structured instructional design that emphasizes higher-order cognitive engagement. Educators should integrate more complex, open-ended, and problem-based tasks into digital worksheets to stimulate deeper analytical thinking.

Third, the use of real-life contexts, such as online shopping, demonstrates the potential of contextual learning in increasing student engagement and relevance of learning materials. This implies that contextualization should be considered a key component in designing meaningful learning experiences. Furthermore, the results suggest that the effectiveness of digital learning tools depends on the alignment between media design, pedagogical strategies, and learning objectives. Teachers play a crucial role in facilitating the use of digital media, particularly in providing scaffolding and guiding students through complex tasks. Therefore, professional development programs for teachers are necessary to enhance their ability to integrate technology effectively into classroom instruction. In addition, the findings indicate that sufficient implementation time is essential to observe significant improvements in higher-order thinking skills. This implies that future instructional designs should consider longer and more sustained interventions. The study also highlights the importance of adapting digital learning tools to students' readiness and prior experience with technology. Finally, this research contributes to the broader understanding that interactive and contextualized digital media can be optimized to support both cognitive and metacognitive development when implemented through well-designed and pedagogically sound approaches.

Limitations and Suggestions for Future Research

This study has several limitations that should be considered when interpreting the findings and designing future research. First, the duration of the intervention was relatively short, which may have limited the ability to observe significant improvements in higher-order cognitive skills such as mathematical critical thinking. Second, the sample was restricted to a single school context, which may reduce the generalizability of the findings to broader educational settings. Third, the quasi-experimental design, although appropriate for classroom research, does not fully control for all external variables that may influence student learning outcomes. Fourth, the similarity of initial abilities between the experimental and control groups may have contributed to the non-significant differences in critical thinking outcomes. Fifth, the E-LKPD tasks may not have been sufficiently complex to stimulate deeper analytical and evaluative thinking processes. Sixth, students' varying levels of familiarity with digital learning platforms may have influenced their ability to optimally engage with the intervention. Seventh, the role of the teacher as a facilitator was not extensively controlled, which may have affected the consistency of implementation across groups. Based on these limitations, future research is recommended to extend the duration of implementation to capture long-term effects on both cognitive and metacognitive development. Further studies should also involve a larger and more diverse sample to improve the generalizability of the findings. Additionally, integrating E-LKPD with more cognitively demanding instructional models, such as problem-based or inquiry-based learning, is suggested to enhance critical thinking outcomes. Future research should also consider incorporating adaptive features and differentiated tasks to accommodate students' diverse abilities and learning needs. Finally, a more in-depth examination of teacher facilitation strategies and their interaction with digital learning media is needed to better understand how to maximize the effectiveness of technology-enhanced learning environments.

CONCLUSION

This study concludes that the development and implementation of contextualized E-LKPD integrated with the Liveworksheets platform provide meaningful contributions to mathematics learning. The developed learning media has been proven to meet the criteria of validity and practicality based on expert validation and user responses. The findings indicate that the use of E-LKPD has a positive impact on students' learning experiences, particularly in promoting engagement and interaction during the learning process. However, the results show that the improvement in mathematical critical thinking skills between the experimental and control groups was not

statistically significant. This suggests that the intervention alone was not sufficient to produce measurable changes in higher-order cognitive outcomes within the given timeframe. In contrast, the study found a significant improvement in students' self-regulated learning in the experimental group compared to the control group. This indicates that the use of interactive and contextual digital worksheets effectively supports students' ability to manage their own learning processes. The integration of real-life contexts, such as online shopping scenarios, contributed to making learning more meaningful and relevant to students' daily experiences. These findings highlight that digital learning media are more immediately impactful on metacognitive aspects than on complex cognitive skills. Therefore, the effectiveness of E-LKPD depends on the alignment between instructional design, task complexity, and implementation strategies. The study also emphasizes the importance of teacher facilitation in guiding students to maximize the benefits of digital learning tools. Overall, this research demonstrates that contextualized E-LKPD using Liveworksheets has strong potential to enhance independent learning while requiring further optimization to significantly improve students' critical thinking skills.

AUTHOR CONTRIBUTIONS STATEMENT

Helmy Wahyu Widiarti designed the study, developed the contextualized digital worksheets (E-LKPD) integrated with the Liveworksheets platform, and led the research and development process using the ADDIE model, including validation, implementation, and data analysis of students' mathematical critical thinking and self-regulated learning. Anton Jaelani contributed to the conceptual framework of technology-enhanced and contextual mathematics learning, refined the instructional design and research methodology, and supported the statistical analysis, including normality, homogeneity, and independent samples t-test. All authors contributed to writing, reviewed the manuscript critically for important intellectual content, and approved the final version.

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