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Integrating culturally responsive teaching into digital worksheets: enhancing students' algebraic thinking and self-confidence in mathematics learning

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Abstract

Background: The limited use of culturally relevant and technology-integrated learning media in mathematics classrooms often results in low student engagement, weak algebraic understanding, and reduced self-confidence. Conventional worksheets tend to emphasize procedural knowledge without connecting learning to students' cultural contexts, leading to less meaningful learning experiences.
Aims: This study aims to develop and evaluate a Culturally Responsive Teaching (CRT)-based electronic student worksheet (e-LKPD) that is valid, practical, and effective in enhancing students' algebraic thinking skills and self-confidence.
Method: This study employed a Research and Development (R&D) approach using the 4D model, consisting of define, design, develop, and disseminate stages. The participants were 84 eighth-grade students. Data were collected through interviews, validation sheets, questionnaires, and algebraic thinking tests. Data analysis involved descriptive statistics and inferential analysis, including normality, homogeneity, and independent t-tests.
Results: The findings indicate that the developed CRT-based e-LKPD is valid (83%) and highly practical (90%). Moreover, the implementation of the e-LKPD significantly improved students' algebraic thinking skills ($p = 0.032 < 0.05$) and self-confidence ($p = 0.001 < 0.05$), with better performance observed in the experimental group compared to the control group.
Conclusion: The CRT-based e-LKPD is an effective instructional innovation that enhances both cognitive and affective learning outcomes, supporting meaningful and engaging mathematics learning.

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INTRODUCTION

Algebraic thinking skills and self-confidence are two essential aspects in mathematics learning that are closely related in influencing students' academic achievement. In mathematics education, algebraic thinking is not limited to mastering formulas or computational procedures but also involves the ability to think abstractly and analytically (A. Alam & Mohanty, 2024; Bråting & Kilhamn, 2021; Kieran, 2022; Sibgatullin et al., 2022). These skills enable students to identify patterns, formulate generalizations, and solve problems in various real-life situations. Mastery of algebra plays a crucial role in developing logical reasoning and preparing students to face increasingly complex challenges in the modern era (A. Alam & Mohanty, 2024; Harel, 2025; Jamil et al., 2025; Sibgatullin et al., 2022). However, many students still struggle to understand algebraic concepts due to their abstract nature. Learning is often dominated by procedural approaches that emphasize memorization rather than conceptual understanding (Arievitch, 2020; Bryce & Blown, 2024; Hurrell, 2021; Hussein & Csíkos, 2023). As a result, students find it difficult to connect mathematical concepts with real-world contexts. This condition leads to low engagement and

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limited participation in classroom activities. Furthermore, students tend to rely on fixed procedures instead of developing flexible problem-solving strategies. Therefore, improving algebraic thinking skills remains a significant challenge in mathematics education.

In addition to cognitive aspects, self-confidence is an important psychological factor that influences students' success in learning mathematics. Self-confidence encourages students to actively participate in learning, ask questions, and express their ideas without hesitation. Students who possess strong self-confidence tend to show persistence and resilience when facing challenging mathematical problems. Conversely, students with low self-confidence often experience anxiety and doubt their own abilities. This condition can result in passive learning behavior and a reluctance to engage in problem-solving activities. As a consequence, their academic performance may not reflect their actual potential. In many classrooms, affective aspects such as self-confidence are not given sufficient attention. Instructional practices often focus more on cognitive achievement while overlooking students' emotional readiness. This imbalance limits students' ability to fully benefit from the learning process. Therefore, it is important to design learning environments that simultaneously support both cognitive and affective development.

The rapid development of digital technology provides opportunities to improve mathematics learning through more interactive and flexible learning media. Digital learning tools allow students to access learning materials anytime and anywhere, making learning more accessible and engaging (Dash, 2022; Kiryakova, 2022). One form of digital learning media that can be utilized is electronic student worksheets, which integrate multimedia elements and interactive activities (Krismadinata et al., 2022; Sinaga et al., 2022). These tools can facilitate student-centered learning and encourage active participation in the learning process. In addition, the Culturally Responsive Teaching approach emphasizes the importance of connecting learning content with students' cultural backgrounds and daily experiences (Anyichie et al., 2023; Berlian & Huda, 2022; Chang & Viesca, 2022; Hernandez, 2022; Markey et al., 2021; Shih, 2024). By integrating cultural relevance into learning, students are more likely to find the material meaningful and relatable. This approach also fosters a sense of belonging and increases students' motivation to learn. However, many existing digital learning tools are not designed to incorporate cultural aspects. Similarly, culturally responsive teaching practices are often implemented without the support of technology. This separation reduces the potential effectiveness of both approaches. Therefore, integrating culturally responsive teaching with digital learning media is expected to create a more meaningful and effective learning environment.

Recent studies have widely explored key dimensions of mathematics education, including the role of Culturally Responsive Teaching (CRT) in fostering inclusive and culturally meaningful learning environments (Abdulrahim & Orosco, 2020; Kolovou, 2023), as well as the integration of digital technology to enhance student engagement and learning outcomes in mathematics (Alabdulaziz, 2021; Drijvers & Sinclair, 2024). In parallel, substantial research has examined algebraic thinking as a fundamental component of mathematical reasoning and cognitive development among students (Pitta-Pantazi et al., 2020; Sun et al., 2023), while other studies have emphasized the importance of mathematics self-efficacy in influencing students' achievement, motivation, and persistence in problem-solving (Özcan & Kültür, 2021; Zakariya, 2022; Živković et al., 2023). However, these research streams are largely conducted in isolation, where CRT studies primarily focus on cultural inclusivity without integrating digital learning tools, and digital learning research tends to emphasize cognitive outcomes without considering cultural responsiveness. Similarly, studies on algebraic thinking and self-efficacy often address cognitive and affective aspects separately, with limited attention to their simultaneous development within a unified instructional design. Consequently, there remains a significant gap in the literature regarding the integration of culturally responsive pedagogy, digital learning media, algebraic thinking skills, and self-efficacy into a single comprehensive learning framework, particularly in the context of secondary mathematics education.

Based on these considerations, this study aims to develop and evaluate a Culturally Responsive Teaching-based electronic student worksheet as an innovative learning medium in mathematics education. The study focuses on examining the validity, practicality, and effectiveness of the developed digital

worksheet. In particular, the research aims to improve students' algebraic thinking skills as a key cognitive outcome. At the same time, this study seeks to enhance students' self-confidence as an important affective factor in learning mathematics. The integration of culturally responsive teaching principles is expected to make learning more contextual and meaningful for students. In addition, the use of digital media is intended to increase student engagement and participation in the learning process. This study also aims to provide an alternative instructional strategy that combines pedagogy and technology. Furthermore, it seeks to contribute to the development of innovative learning designs in mathematics education. The findings are expected to provide empirical evidence regarding the effectiveness of integrating cultural and technological approaches. Ultimately, this research aims to support the creation of inclusive, engaging, and high-quality mathematics learning environments.

LITERATURE REVIEW

Algebraic thinking is widely recognized as a fundamental component of mathematical cognition that supports students' ability to reason abstractly and solve complex problems. It involves the capacity to identify patterns, express relationships symbolically, and generalize mathematical ideas across different contexts (Ellis et al., 2022; Hunter & Miller, 2022a; Varhol et al., 2021). These skills are essential for transitioning from arithmetic to more advanced mathematical concepts. Students who develop strong algebraic thinking are better equipped to engage in logical reasoning and analytical problem-solving (Kusuma et al., 2024; Pitta-Pantazi et al., 2020; Sibgatullin et al., 2022). However, many learners experience difficulties in constructing meaningful algebraic representations due to the abstract nature of the subject. This challenge is often exacerbated by instructional approaches that emphasize procedural fluency over conceptual understanding. As a result, students may rely on memorization rather than developing flexible thinking strategies. Effective mathematics instruction should therefore focus on promoting conceptual understanding through meaningful learning experiences (Koskinen & Pitkäniemi, 2022; Ncube & Luneta, n.d.; Polman et al., 2021). The development of algebraic thinking requires learning environments that encourage exploration, reasoning, and reflection. Consequently, instructional innovations are needed to support students in developing deeper mathematical understanding.

Self-confidence, often conceptualized as self-efficacy in educational contexts, plays a significant role in shaping students' learning behaviors and academic performance. In mathematics learning, self-confidence influences students' willingness to engage in problem-solving activities and participate in classroom discussions. Students with higher levels of self-confidence tend to demonstrate greater persistence when facing challenging tasks (Cuddington et al., 2023). They are also more likely to take risks and explore alternative solutions in mathematical problem-solving. Conversely, students with low self-confidence often experience anxiety and avoid engaging in complex tasks. This avoidance behavior can negatively impact their learning outcomes and limit their academic potential. The relationship between self-confidence and achievement is reciprocal, where success can enhance confidence and confidence can improve performance (Jekauc et al., 2025; Lochbaum et al., 2022). Despite its importance, self-confidence is often underemphasized in traditional instructional practices. Many teaching approaches prioritize cognitive achievement while neglecting affective development. Therefore, it is essential to design learning environments that foster both confidence and competence simultaneously.

The integration of digital technology in education has transformed the way mathematics is taught and learned. Digital learning media provide opportunities for interactive and student-centered learning experiences that can enhance engagement and motivation (D. A. Alam, 2023; Bhardwaj et al., 2025; Kerimbayev et al., 2023). Electronic student worksheets represent one form of digital innovation that supports active learning through structured activities and multimedia

integration (Budiarti et al., 2025). These tools allow for flexibility in learning, enabling students to access materials beyond the classroom setting. Digital worksheets can incorporate visual, audio, and interactive elements that make abstract mathematical concepts more accessible (Radović et al., 2020). Furthermore, technology-enhanced learning environments encourage collaboration and independent exploration (Demir & Zengin, 2023; Ioannou & Ioannou, 2020; Su & Zou, 2022). The use of digital media also supports differentiated instruction by accommodating diverse learning needs. However, the effectiveness of digital tools depends on how well they are integrated into instructional design. Simply digitizing traditional materials without pedagogical innovation may not yield significant improvements. Therefore, the design of digital learning media must align with sound pedagogical principles to maximize learning outcomes.

Culturally Responsive Teaching is an instructional approach that emphasizes the importance of incorporating students' cultural backgrounds into the learning process. This approach recognizes that students bring diverse experiences, values, and perspectives into the classroom. By integrating cultural relevance into instruction, teachers can create more meaningful and inclusive learning environments. In mathematics education, culturally responsive teaching helps students connect abstract concepts with real-life experiences (Hunter & Miller, 2022b; Stone et al., 2025; Tanase, 2022). This connection enhances students' understanding and engagement in learning. Additionally, culturally responsive practices promote a sense of belonging and respect for diversity (Ialuna et al., 2024; Markey et al., 2021). Students who feel valued are more likely to participate actively and develop confidence in their abilities. However, the implementation of culturally responsive teaching requires careful planning and adaptation of instructional materials. Teachers must design learning activities that reflect students' cultural contexts while maintaining academic rigor. Therefore, integrating cultural responsiveness into instructional media presents an opportunity to enhance both engagement and learning outcomes.

The integration of Culturally Responsive Teaching with digital learning media represents a promising approach to improving mathematics education. Combining these two elements allows for the creation of learning environments that are both interactive and culturally meaningful. Digital worksheets designed with culturally responsive principles can provide contextualized learning experiences that resonate with students' backgrounds. This integration supports both cognitive development, such as algebraic thinking, and affective development, such as self-confidence. By embedding cultural elements into digital platforms, learning becomes more relevant and engaging for students. Moreover, technology enables the delivery of culturally responsive content in flexible and accessible ways. Despite its potential, the integration of CRT and digital media is still relatively underexplored in mathematics education research. Many studies have examined these components separately rather than as a unified instructional approach. This gap highlights the need for research that combines pedagogical and technological innovations. Therefore, developing CRT-based digital worksheets is expected to provide a comprehensive solution for enhancing mathematics learning outcomes.

METHOD

Research Design

This study employed a Research and Development (R&D) approach to design and evaluate a Culturally Responsive Teaching (CRT)-based electronic student worksheet (e-LKPD) as an innovative instructional medium in mathematics learning. The development process adopted the 4D model, which consists of four systematic stages: define, design, develop, and disseminate. In the define stage, an initial analysis was conducted to identify students' characteristics, analyze instructional problems, and determine the objectives of product development. In the design stage,

research instruments were prepared, appropriate learning media were selected, and the format of the e-LKPD was determined. The prototype design included key components such as the cover, instructions for use, learning materials, and student activities aligned with algebraic thinking indicators. In the develop stage, the prototype underwent expert validation involving specialists in mathematics education, instructional design, and interactive media. This validation process ensured that the developed product met quality standards and aligned with students' needs. After validation, a limited trial was conducted to evaluate the practicality of the product through student responses. The effectiveness of the CRT-based e-LKPD was subsequently tested through a quasi-experimental design involving experimental and control groups. The disseminate stage involved introducing the final product to mathematics teachers through professional forums to support wider implementation.

Participant

The participants in this study were eighth-grade students of SMP Negeri 2 Cilongok, which consists of nine classes at the same grade level. A total of 84 students were involved in different stages of the research. In the limited trial stage, one class (Class VIII D) consisting of 28 students participated in testing the practicality of the e-LKPD. For the effectiveness testing stage, two classes were selected using a cluster random sampling technique. The selected classes were Class VIII E as the experimental group and Class VIII H as the control group, each consisting of 28 students. The experimental group received instruction using the CRT-based e-LKPD integrated with a Problem-Based Learning (PBL) model. Meanwhile, the control group was taught using the same PBL model but supported by conventional learning media in the form of interactive PowerPoint presentations. Both groups were assumed to have relatively similar academic backgrounds, ensuring comparability in the analysis.

Instrument

Data were collected using multiple instruments to capture both cognitive and affective learning outcomes. These instruments included interview guidelines, validation sheets, student response questionnaires, observation sheets, algebraic thinking tests, and self-confidence questionnaires. Interview guidelines were used in the define stage to identify learning problems and students' needs. Validation sheets were used by experts to assess the quality of the e-LKPD in terms of content and media design. Student response questionnaires were used to evaluate the practicality of the product. Observation sheets were used to monitor the implementation of learning activities in both experimental and control groups. The algebraic thinking test was designed based on three key indicators: pattern seeking, pattern recognition, and generalization. These indicators measure students' ability to analyze problems, represent mathematical relationships, and draw conclusions. The detailed description of these indicators is presented in Table 1.

Table 1. Description of algebraic thinking skill indicators

Indicator	Description
Pattern seeking	Students' ability to analyze information from a given problem
Pattern recognition	Students' ability to represent information in mathematical form
Generalization	Students' ability to apply mathematical findings to reach conclusions

At the end of the learning process, all students were given an algebraic thinking test and a self-confidence questionnaire. These instruments were used to determine the effectiveness of the CRT-based e-LKPD in improving students' learning outcomes.

Data Analysis

Data analysis in this study involved both qualitative and quantitative approaches. Qualitative data obtained from interviews were analyzed descriptively to identify initial learning conditions and

instructional needs. Quantitative data from validation sheets and questionnaires were analyzed using descriptive statistics to determine the validity and practicality of the e-LKPD. The validity test involved three validators consisting of one mathematics teacher and two lecturers. A Likert scale ranging from 1 to 4 was used, where 1 indicates strongly disagree and 4 indicates strongly agree. The categorization of validity scores is presented in Table 2.

Table 2. Validity test categorization

Percentage (%)	Category
85 – 100	Very Valid
70 – 84	Valid
55 – 69	Less Valid
< 55	Not Valid

The e-LKPD was considered valid if the obtained score exceeded 75%. Practicality was assessed based on student response questionnaires. The criteria for practicality are presented in Table 3.

Table 3. Practicality test score analysis

Percentage (%)	Category
85 – 100	Very Practical
70 – 84	Practical
60 – 69	Less Practical
< 60	Not Practical

The e-LKPD was considered practical if the average score exceeded 60%. For effectiveness testing, inferential statistical analysis was conducted using SPSS. Prior to hypothesis testing, normality and homogeneity tests were performed to ensure that the data met statistical assumptions. The independent t-test was then used to compare the mean scores of the experimental and control groups. The significance level was set at 0.05. The e-LKPD was considered effective if the significance value (Sig. 2-tailed) was less than 0.05.

Procedure

The research procedure followed the four stages of the 4D model. In the define stage, preliminary observations and interviews were conducted to identify learning problems and analyze students' needs. In the design stage, the structure and content of the e-LKPD were developed, including learning objectives, instructions, and activities based on CRT principles. In the develop stage, the prototype was validated by experts and revised based on their feedback. A limited trial was then conducted to evaluate the practicality of the product. Following this, the e-LKPD was implemented in the experimental class, while the control class used conventional learning media. During implementation, data were collected through tests, questionnaires, and observations. The collected data were analyzed to determine the effectiveness of the product in improving algebraic thinking skills and self-confidence. In the disseminate stage, the final product was introduced to mathematics teachers through professional forums to support broader application.

Figure 1. Research method flow

RESULTS AND DISCUSSION

Results

The results of the needs analysis revealed that mathematics learning, particularly in algebra topics, is still dominated by conventional worksheets that emphasize procedural exercises without contextual or cultural relevance. Interviews with teachers indicated that students tend to memorize formulas without fully understanding underlying concepts. In addition, students demonstrated low levels of self-confidence, as reflected in their reluctance to participate in discussions and their fear of making mistakes. Furthermore, learning media used in the classroom were mostly limited to printed worksheets and presentation slides, which lacked interactivity and accessibility outside the classroom. Although the school has adequate technological facilities, such as interactive panels, these resources have not been optimally utilized. These findings indicate a strong need for the development of digital and culturally responsive learning media to support meaningful and engaging mathematics learning.

Product

The developed product was a CRT-based electronic student worksheet (e-LKPD) designed to integrate algebraic thinking skills with culturally relevant learning contexts. The structure of the e-LKPD includes learning objectives, instructions, and three main activity sections aligned with algebraic thinking indicators.

Table 4. Design of CRT Based e-LKPD

No	Component	Description
1	Identity Section	Cover page, author identity, and student identity
2	Instruction Section	Learning objectives, instructions for use, and group identity
3	Activity 1	Algebraic thinking problems based on CRT
4	Activity 2	Contextual problems in livestock settings

The integration of local cultural contexts in learning activities allows students to engage more meaningfully with mathematical concepts.

Product Validity

The validation results from experts indicated that the developed e-LKPD met the validity criteria in both content and media aspects.

Table 5. Summary of product validity

Aspect	Score	Percentage	Category
Content Validity	89	82%	Valid
Media Validity	83	84%	Valid
Average	86	83%	Valid

The results show that the CRT-based e-LKPD is appropriate for use in mathematics learning.

Product Practicality

The practicality test involved 28 students and evaluated technical usability, visual design, and content clarity.

Table 6. Summary of practicality test

Indicator	Average Score	Percentage	Category
Technical Aspect	45	90%	Very Practical
Visual Aspect	-	-	Very Practical
Content	-	-	Very Practical
Overall	45	90%	Very Practical

The results indicate that the e-LKPD is highly practical and easy to use in classroom learning.

Effectiveness testing

The results of prerequisite testing indicated that all data were normally distributed and homogeneous.

Table 7. Normality test results (posttest)

Class	Statistic	Sig.	Interpretation
Control	0.941	0.115	Normal
Experimental	0.934	0.077	Normal

The homogeneity test also showed that the variance between groups was equal (Sig. > 0.05), indicating that the data met the assumptions for further analysis.

Descriptive statistics

Table 8. Descriptive statistics of algebraic thinking

Group	Mean Score
Control	82.36
Experimental	85.43

Table 9. Descriptive statistics of self confidence

Group	Mean Score
Control	27.43
Experimental	28.89

The experimental group consistently achieved higher scores than the control group in both variables.

Hypothesis Testing

Table 10. Independent t-test results

Variable	Sig. (2-tailed)	Result
Algebraic Thinking	0.032	Significant
Self-Confidence	0.001	Significant

The results show that the significance values for both variables are below 0.05, indicating a statistically significant difference between the experimental and control groups.

Dissemination Results

The dissemination stage involved mathematics teachers in a professional forum to evaluate the applicability of the developed product.

Table 11. Teachers responses to e-LKPD

Aspect	Percentage
Attractive and Communicative	80.45%
Innovative Solution	86%
Flexibility in Access	90%
Improved Learning Outcomes	88.4%

The highest rating was obtained for flexibility in access, indicating that the digital format of the e-LKPD is highly suitable for modern learning environments.

Discussion

The findings of this study indicate that the CRT-based e-LKPD is effective in enhancing students' algebraic thinking skills, as reflected in the higher posttest scores of the experimental group compared to the control group. This result suggests that integrating culturally relevant contexts into learning materials can support deeper conceptual understanding. Students are able to connect abstract algebraic concepts with familiar real-life situations, making learning more meaningful (A. Alam & Mohanty, 2024; Montesdeoca, 2023). This finding aligns with previous research that highlights the importance of contextual learning in improving mathematical reasoning. However, unlike earlier studies that primarily focused on contextualization without technological integration, this study demonstrates the added value of combining cultural relevance with digital learning media. The interactive nature of the e-LKPD also contributes to students' engagement during the learning process. Students are not only passive recipients of information but actively involved in problem-solving activities. This active engagement plays a significant role in strengthening algebraic thinking skills. Furthermore, the structured design of the worksheet helps guide students through the stages of pattern recognition and generalization. Therefore, the integration of CRT and digital media provides a more comprehensive learning experience compared to conventional approaches.

In terms of affective outcomes, the results show that the CRT-based e-LKPD significantly improves students' self-confidence. Students in the experimental group demonstrated higher confidence levels compared to those in the control group. This improvement can be attributed to the learning environment created through culturally responsive teaching. When students feel that their cultural background is acknowledged, they are more likely to develop a sense of belonging in the classroom. This sense of belonging encourages them to participate actively and express their ideas. Previous studies have also reported that culturally responsive teaching can enhance students' motivation and emotional engagement. However, many of these studies did not integrate digital tools to support learning. This study extends previous findings by showing that the combination of CRT and digital worksheets can further strengthen students' confidence. The flexibility of digital learning allows students to learn at their own pace, reducing anxiety and increasing comfort. In addition, interactive features in the e-LKPD provide immediate feedback, which helps students build confidence in their abilities. Thus, the integration of cultural relevance and technology creates a supportive learning environment that fosters both confidence and competence.

The high level of validity and practicality of the developed e-LKPD indicates that the product is well-designed and suitable for classroom implementation. Expert validation results confirm that the content, structure, and media design meet educational standards (Barari et al., 2022; Gutiérrez-Castillo et al., 2023). This finding is consistent with previous research that emphasizes the importance of systematic instructional design in developing effective learning materials (Abuhassna et al., 2024; Martin et al., 2020; Spatioti et al., 2022). The practicality results also show that students

find the e-LKPD easy to use and engaging. This suggests that the design successfully accommodates students' needs and preferences. Compared to traditional worksheets, the digital format offers greater flexibility and accessibility (Huda, 2023). Students can interact with the material in a more dynamic way, which enhances their learning experience (Nguyen et al., 2024). Previous studies on digital learning media have also highlighted similar advantages, particularly in terms of engagement and usability. However, this study differs by embedding culturally responsive elements within the digital design. This integration ensures that the learning material is not only functional but also meaningful for students. Therefore, the combination of validity and practicality supports the effectiveness of the e-LKPD as an instructional tool.

The results of this study also demonstrate the effectiveness of combining the CRT approach with the Problem-Based Learning model. This combination allows students to engage in authentic problem-solving activities that reflect real-world situations. Problem-Based Learning encourages students to think critically and collaboratively. When combined with CRT, these problems become more relevant to students' cultural contexts. This relevance increases students' interest and motivation in learning mathematics. Previous research has shown that PBL can improve students' problem-solving skills, but its effectiveness depends on the context in which it is applied. In this study, the integration of CRT enhances the effectiveness of PBL by providing meaningful contexts for problem-solving. Students are more motivated to explore solutions when the problems are connected to their daily lives. Additionally, the use of digital worksheets supports the implementation of PBL by providing structured guidance. This structured approach helps students navigate complex problems more effectively. Therefore, the combination of CRT, PBL, and digital media creates a powerful instructional framework.

Despite the positive findings, several limitations should be considered in interpreting the results of this study. First, the study was conducted in a single school, which may limit the generalizability of the findings. Different school contexts may produce different results depending on students' backgrounds and available resources. Second, the study focused only on algebraic thinking and self-confidence, without examining other important variables such as motivation or critical thinking. Third, the duration of the intervention was relatively short, which may not fully capture long-term learning effects. Previous studies have suggested that sustained interventions are necessary to achieve lasting improvements. In addition, the implementation relied on the availability of technological facilities, which may not be equally accessible in all schools. Future research should consider involving a larger and more diverse sample to enhance generalizability. It is also recommended to explore additional learning outcomes to provide a more comprehensive understanding of the impact of CRT-based digital learning. Longitudinal studies could be conducted to examine the long-term effectiveness of the approach. Furthermore, future studies may investigate the integration of other instructional models with CRT and digital media. Therefore, while this study provides important insights, further research is needed to expand and validate its findings.

Implications

The findings of this study provide important implications for the development of mathematics learning, particularly in integrating pedagogical approaches with digital technology. The effectiveness of the CRT-based e-LKPD indicates that culturally relevant learning materials can significantly enhance students' understanding of abstract mathematical concepts. This suggests that mathematics instruction should move beyond procedural teaching toward more contextual and meaningful learning experiences. The integration of cultural elements into learning materials allows students to relate mathematical concepts to their daily lives, thereby improving engagement and comprehension. In addition, the use of digital worksheets demonstrates that technology can facilitate flexible and interactive learning environments. This flexibility enables students to access learning

materials anytime, which supports independent and self-paced learning. From an affective perspective, the improvement in students' self-confidence highlights the importance of addressing psychological factors in instructional design. Learning environments that are inclusive and culturally responsive can foster a sense of belonging, which positively influences students' participation and motivation. The combination of CRT and digital media also provides a practical framework for teachers to implement innovative teaching strategies in mathematics classrooms. Furthermore, the integration of Problem-Based Learning with CRT-based e-LKPD supports the development of higher-order thinking skills through authentic problem-solving activities. These findings imply that teachers should consider adopting integrated instructional approaches that simultaneously address cognitive and affective learning outcomes. Therefore, this study contributes to the advancement of mathematics education by providing a model for designing inclusive, technology-enhanced, and student-centered learning environments.

Limitations and Suggestions for Future Research

This study has several limitations that should be considered when interpreting the findings. First, the research was conducted in a single junior high school, which may limit the generalizability of the results to other educational contexts. Differences in school environments, student characteristics, and available resources may influence the effectiveness of the developed e-LKPD. Second, the sample size was relatively limited, involving only 84 students, which may not fully represent broader student populations. Third, the study focused specifically on algebraic thinking skills and self-confidence, without examining other important variables such as critical thinking, problem-solving ability, or learning motivation. Fourth, the duration of the intervention was relatively short, which may not capture the long-term impact of the CRT-based e-LKPD on students' learning outcomes. In addition, the implementation relied on the availability of digital facilities, which may not be equally accessible in all schools. The use of self-report questionnaires to measure self-confidence may also introduce subjectivity in the data. Furthermore, the study did not explore the role of teacher readiness and competence in implementing CRT-based digital learning effectively. Based on these limitations, future research is recommended to involve larger and more diverse samples across different educational settings. Longitudinal studies are also needed to examine the sustainability of learning outcomes over time. Future studies may expand the scope by investigating additional cognitive and affective variables. Moreover, further research should explore the integration of CRT-based digital learning with other instructional models to enhance its effectiveness.

CONCLUSION

This study concludes that the development of a Culturally Responsive Teaching (CRT)-based electronic student worksheet (e-LKPD) provides an effective instructional innovation in mathematics learning. The product demonstrated a high level of validity, indicating that its content and design are appropriate and aligned with learning objectives. In addition, the e-LKPD showed strong practicality, as reflected in positive student responses regarding its usability and attractiveness. The implementation of the CRT-based e-LKPD significantly improved students' algebraic thinking skills compared to conventional learning methods. Students were better able to identify patterns, represent mathematical relationships, and generalize concepts through contextualized learning activities. Furthermore, the integration of culturally relevant contexts contributed to deeper conceptual understanding. The results also revealed a significant improvement in students' self-confidence during mathematics learning. Students became more active, confident, and willing to participate in problem-solving activities. The combination of CRT principles and digital learning media created a more engaging and meaningful learning environment.

The integration of Problem-Based Learning further supported the development of higher-order thinking skills. Overall, this study demonstrates that combining pedagogy, culture, and technology can enhance both cognitive and affective learning outcomes. Therefore, the CRT-based e-LKPD can be recommended as an innovative learning tool to improve the quality of mathematics education.

AUTHOR CONTRIBUTIONS STATEMENT

Haryanto Pamungkas designed the study, developed the Culturally Responsive Teaching (CRT)-based electronic student worksheet (e-LKPD), and led the Research and Development process using the 4D model, including data analysis on algebraic thinking and self-confidence outcomes. Gunawan contributed to the development of the theoretical framework on culturally responsive teaching and digital learning integration, refined the instructional design of the e-LKPD, and supported the statistical analysis, including validity, practicality, and effectiveness testing through inferential analysis. All authors contributed to writing, reviewed the manuscript critically for important intellectual content, and approved the final version.

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