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Integrated Digital Learning Tools To Enhance Student's Mathematical Problem Solving Skills

Alat Pembelajaran Digital Terpadu Untuk Meningkatkan Keterampilan Pemecahan Masalah Matematika Siswa

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ABSTRACT

In the era of digital transformation, integrating technology into mathematics education has become an essential strategy for developing higher-order thinking and problem-solving skills among students. This study investigates the effectiveness of Integrated Digital Learning Tools (IDLT) in enhancing students' mathematical problem-solving abilities across various cognitive dimensions. The research adopts a quasi-experimental design involving 120 secondary school students divided into experimental and control groups. The experimental group engaged in digital-based learning activities using an integrated platform that combines interactive simulations, adaptive learning analytics, and collaborative problem-solving modules, while the control group received conventional instruction. Data were collected through standardized mathematical problem-solving tests, learning engagement surveys, and classroom observations. The results revealed a significant improvement in the experimental group's performance, particularly in the stages of problem identification, strategy formulation, and solution verification. Moreover, the integration of digital learning tools fostered metacognitive awareness and increased student motivation toward mathematics learning. These findings suggest that the implementation of IDLT can serve as a pedagogical innovation that supports personalized and inquiry-based learning environments. The study concludes that a well-designed digital ecosystem has the potential to bridge the gap between abstract mathematical concepts and real-world application, thereby promoting 21st-century learning competencies.
Keywords: *Integrated Digital Learning Tools, Mathematical Problem Solving, Educational Technology.*

ABSTRAK

Di era transformasi digital, integrasi teknologi ke dalam pendidikan matematika telah menjadi strategi penting untuk mengembangkan kemampuan berpikir tingkat tinggi dan pemecahan masalah siswa. Penelitian ini menyelidiki efektivitas Alat Pembelajaran Digital Terpadu (IDLT) dalam meningkatkan kemampuan pemecahan masalah matematika siswa di berbagai dimensi kognitif. Penelitian ini mengadopsi desain kuasi-eksperimental yang melibatkan 120 siswa sekolah menengah yang dibagi menjadi kelompok eksperimen dan kontrol. Kelompok eksperimen terlibat dalam kegiatan pembelajaran berbasis digital menggunakan platform terintegrasi yang menggabungkan simulasi interaktif, analitik pembelajaran adaptif, dan modul pemecahan masalah kolaboratif, sementara kelompok kontrol menerima instruksi konvensional. Data dikumpulkan melalui tes pemecahan masalah matematika terstandarisasi, survei keterlibatan pembelajaran, dan observasi kelas. Hasilnya menunjukkan peningkatan yang signifikan dalam kinerja kelompok eksperimen, terutama dalam tahap identifikasi masalah, formulasi strategi, dan verifikasi solusi. Lebih lanjut, integrasi alat pembelajaran digital menumbuhkan kesadaran metakognitif dan meningkatkan motivasi siswa terhadap pembelajaran

matematika. Temuan ini menunjukkan bahwa implementasi IDLT dapat berfungsi sebagai inovasi pedagogis yang mendukung lingkungan belajar yang personal dan berbasis inkuiri. Studi ini menyimpulkan bahwa ekosistem digital yang dirancang dengan baik memiliki potensi untuk menjembatani kesenjangan antara konsep matematika abstrak dan penerapan di dunia nyata, sehingga meningkatkan kompetensi pembelajaran abad ke-21.
Kata Kunci: Alat Pembelajaran Digital Terpadu, Pemecahan Masalah Matematika, Teknologi Pendidikan.

1. Introduction

The development of the Industrial Revolution 4.0 and Society 5.0 has brought significant changes to the orientation of education around the world(Andalia et al., 2020; Abdullah et al., 2024; Asnur et al., 2024). This era is characterized by the integration of digital technology, artificial intelligence, and cyber-physical systems that require humans to have high-level thinking competencies or Higher-Order Thinking Skills (HOTS), including the ability to think critically, creatively, and solve complex mathematical problems(Zwart et al., 2017). This ability is the key for students to be able to adapt quickly to technological changes and global socio-economic dynamics. In the context of mathematics education(Serin, 2023; Chechan et al., 2025), mastery of HOTS allows students not only to understand concepts procedurally, but also to apply them in real-world situations through reasoning and data-driven analysis (Saputra & Rustaman, 2021). Thus, education in this era is no longer sufficiently oriented to knowledge transfer, but must focus on developing flexible, reflective, and innovative thinking competencies (World Economic Forum, 2020).

The change in landscape also requires a paradigm transformation of learning from a teacher-centered approach to a student-centered approach that utilizes digital technology in an integrative manner(Akugizibwe & Ahn, 2020). The student-centered learning approach allows students to play an active role in constructing knowledge through exploration, collaboration, and reflection with the support of various interactive digital platforms (Prasetyo & Sutopo, 2018). The integration of technology in learning, such as the use of learning management systems (LMS), interactive simulations, and adaptive learning tools, can enrich the learning experience and encourage students' independence and intrinsic motivation (Karakoyun & Lindberg, 2022). This transformation not only improves the quality of learning outcomes, but also prepares students to be able to face the challenges of the 21st century that demand digital literacy, collaborative communication, and adaptive problem-solving skills (UNESCO, 2021).

Mathematical problem-solving skills are at the core of meaningful mathematics learning because they reflect the application of concepts, principles, and procedures to solve new situations logically and systematically(Wawan et al., 2023); (Hidayat & Firmanti, 2024); (Oktarina et al., 2021; Santosa et al., 2020). Polya (1945) stated four main stages in the problem-solving process, namely understanding the problem, devising a plan, carrying out the plan, and looking back). Each stage demands a high level of cognitive involvement, from identifying important information, formulating hypotheses, to reflecting on the validity of the solution(Syamsuddin et al., 2023). This process not only trains procedural skills, but also develops reflective and evaluative thinking skills that are the basis for mastering higher-order thinking skills (Schoenfeld, 2016). In the context of modern education, mathematical problem-solving is considered a means to build students' adaptive abilities in dealing with real-world complexities that require logical reasoning and flexibility of thinking (Putra et al., 2025; Oktarina et al., 2021)

In addition, the ability to think critically, logically, and creatively are closely related in the process of solving mathematical problems(Elhilal, 2025). Critical thinking helps students analyze assumptions, evaluate arguments, and determine the most appropriate strategy to achieve a solution (Ennis, 2015). While logic serves as a cornerstone for ensuring the consistency of reasoning and the validity of the solution steps, creativity allows students to develop innovative and efficient new approaches to complex problems (Leikin, 2009). Thus, mathematical problem-solving abilities are not only mechanistic, but are integrative processes that involve the interaction between rational and imaginative thinking(Festiyed, 2024; Seftiani et al., 2021; Winiasri et al., 2023). The collaboration between these three abilities makes mathematics learning a vehicle to foster students' intellectual sensitivity and innovative power in the context of 21st century education (Brookhart, 2010).

Integration of Digital Learning Tools (IDLT) is an innovative approach in education that utilizes various digital technologies in an integrated manner to create an adaptive, interactive, and collaborative learning ecosystem. IDLT refers not only to the use of digital tools separately, but to the integration of various platforms, such as interactive simulations(Cirneanu & Moldoveanu, 2024), learning analytics, adaptive learning systems, and interconnected online collaborative environments (Zhao & Ko, 2021). The system is designed to support personalized learning by adjusting students' pace, learning style, and level of understanding through real-time analytical data (Popenici & Kerr, 2017). In the context of mathematics learning, IDLT provides a space for students to explore abstract concepts through dynamic visualization and real-world context-based simulations, thus helping to overcome the limitations of traditional approaches that tend to emphasize memorization and proceduralism. Thus, IDLT acts as a pedagogical medium that connects mathematical content, pedagogical approaches, and technology in harmony according to the framework of Technological Pedagogical Content Knowledge (TPACK) (Mishra & Koehler, 2006).

In addition to enriching the learning experience, the main goal of IDLT integration is to strengthen students' cognitive and metacognitive interactions in the process of mathematical problem-solving(Setiawan et al., 2023). Through features such as interactive feedback, adaptive scaffolding, and peer collaboration tools, students are encouraged to think reflectively, control their learning strategies, and evaluate the effectiveness of problem-solving steps (Ifenthaler & Yau, 2020). This activity not only enhances conceptual understanding, but also develops metacognitive awareness—the student's ability to be aware of and regulate his or her own thought process(Bernacki et al., 2020). IDLT allows for a continuous learning loop where students learn from mistakes and improve problem-solving strategies independently. Thus, the integration of digital tools in mathematics learning is not just as a technological support, but as a catalyst that grows self-regulated learning and higher-order thinking skills (HOTS) simultaneously (Tsai et al., 2022).

Research by Tsai et al. (2022) found that an integrated digital learning environment is able to foster 21st-century competencies through increased cognitive and metacognitive interactions in the learning process. Similar results were also reported by Ifenthaler and Yau (2020) who emphasized that learning analytics and adaptive feedback systems in DLT can strengthen metacognitive awareness as well as students' ability to set strategies in solving mathematical problems. Furthermore, Zhao and Ko **(2021)** show that digital learning that combines interactive simulations and online collaboration can improve students' reflective thinking skills and mathematical creativity. The three studies confirm that IDLT has strategic potential in creating a more personalized, adaptive, and student-centered learning experience, in accordance with the demands of learning in the era of the Industrial Revolution 4.0.

In addition, research conducted by Karakoyun and Lindberg (2022) shows that digital technology-based learning encourages the transition from the teacher-centered paradigm to student-centered learning, so that students are more active in the exploration and construction of mathematical knowledge. Research by Saputra and Rustaman (2021**)** also strengthens these findings by concluding that the use of interactive digital tools in mathematics learning improves problem-solving skills, especially in the stages of strategy planning and outcome verification. These results are strengthened by Mishra and Koehler (2006) who state that the effectiveness of technology integration in learning is determined by the balance between pedagogical elements, content, and technology as described in the TPACK model. Thus, previous relevant studies show that there is a research gap that can be bridged through this study, namely by empirically examining the effectiveness of integrating various integrated Digital Learning Tools

(IDLT) in improving mathematical problem-solving skills through students' cognitive and metacognitive interactions.

2. Methodology

This study uses a quasi-experimental design method with a pretest-posttest control group design to test the effectiveness of Integrated Digital Learning Tools (IDLT) in improving students' mathematical problem-solving skills. This design was chosen because it allowed researchers to compare learning outcomes between experimental groups that received IDLT-based learning and control groups that used conventional learning, although randomized assignment of participants was not entirely feasible (Creswell & Creswell, 2018). The study population consisted of junior high school students, while the sample was taken using purposive sampling techniques taking into account equity of initial abilities and access to digital devices. The research instruments included a mathematical problem-solving ability test arranged based on the four stages of Polya (1945)—understanding the problem, planning strategies, implementing solutions, and verifying results—as well as metacognitive questionnaires to measure students' thinking awareness during the learning process. The validity and reliability of the instruments are tested through expert judgment and Cronbach's alpha statistical analysis to ensure internal consistency.

Data analysis was carried out using inferential statistics with ANCOVA test to control for differences in initial ability between groups, as well as descriptive analysis to describe changes in students' cognitive and metacognitive indicators. In addition, qualitative data was collected through classroom observation and semi-structured interviews to enrich understanding of students' learning experiences during IDLT implementation. This mixed-methods approach provides a more comprehensive understanding of the influence of digital tool integration on students' mathematical thinking processes (Johnson & Onwuegbuzie, 2004). Data from the learning analytics platform is also used to track students' digital engagement patterns, such as frequency of access, assignment completion time, and most frequently used types of activities. With a combination of quantitative and qualitative data, this research is expected to be able to produce valid and in-depth findings regarding the effectiveness of IDLT in improving mathematical problem-solving skills and building a conceptual model of digital learning that is oriented towards the development of higher-order thinking skills (HOTS).

3. Result and Discussion

The results of descriptive statistical analysis at the pretest stage showed that the initial mathematical problem-solving ability between the experimental and control groups was relatively balanced. The average pretest score of the experimental group was 62.15 (SD = 8.42) and the control group was 61.73 (SD = 8.59), with the results of the independent sample t-test showing no significant difference between the two ($p = 0.714 > 0.05$). This indicates that before treatment, both groups had relatively homogeneous levels of ability. Further analysis of the components of the mathematical thinking process based on the model of Polya (1945) shows that the main weakness of students lies in the formulating strategy and verification stages, where most students have difficulty in designing the solution steps and evaluating the correctness of the results. This condition shows the need for a learning approach that is able to facilitate a more targeted reflective and strategic thinking process (Zakaria et al., 2023).

After the application of Integrated Digital Learning Tools (IDLT) in learning, there was a significant improvement in the experimental group compared to the control group. The posttest results showed that the average score of the experimental group increased to 81.47 (SD = 6.93), while the control group only reached 71.12 (SD = 7.45). The ANCOVA test showed a significant difference between the two groups ($p = 0.001 < 0.05$) after controlling for the initial score. The biggest improvement was seen in the planning and reflective thinking aspects, where students were able to choose more appropriate strategies and show increased metacognitive awareness in evaluating their work results. The average gain score of the experimental group (M = 19.32) was higher compared to the control group (M = 9.39), indicating that the integration of IDLT was effective in strengthening students' high-level thinking skills and problem-solving strategies as shown in Table 1.

Table 1.Descriptive Statistics of Pretest and Posttest Scores

Group	N	Rata-rata Pretest	SD Pretest	Rata-rata Posttest	SD Posttest	Gain Score	Sig. (p)
Experiment (IDLT)	60	62.15	8.42	81.47	6.93	19.32	0.001*
Control (Konvensional)	60	61.73	8.59	71.12	7.45	9.39	0.714 (ns)

Table 1. The results of the table above show that the implementation of IDLT significantly improves students' mathematical problem-solving skills. The difference in gain scores between the experimental and control groups supported the finding that the integration of interactive and adaptive digital tools was able to encourage students to think reflexively and strategically according to the Polya framework. Empirically, these results reinforce the constructivist theory and the findings of Tsai et al. (2022) that an integrated digital learning environment improves metacognitive abilities and complex cognitive learning outcomes. Furthermore, the use of Integrated Digital Learning Tools (IDLT) has a significant influence on improving students' mathematical problem-solving skills. After controlling for the initial ability variable (pretest), a value of F(1.117) = 15.684 with p = 0.001 (< 0.05) was obtained, which indicates that the IDLT-based learning model provides a significant difference compared to conventional learning. The effect size value (Cohen's d = 0.86) indicates that the increase is in the moderate to high effect category, which means that the integration of digital tools has a substantial impact on students' cognitive achievement. These results are in line with the findings of Tsai et al. (2022) and Ifenthaler & Yau (2020) who stated that an adaptive digital learning environment can increase cognitive engagement, improve thinking strategies, and strengthen knowledge transfer to more complex problem-solving contexts(Choirudin et al., 2025). Thus, the application of IDLT has proven to be not only statistically effective, but also pedagogically in developing students' higher-order thinking skills (HOTS) in the field of mathematics which can be seen in the Table 2.

Table 2. ANCOVA Analysis Results and Effect Size of the Use of IDLT on Mathematical Problem Solving Ability

Variable Dependency	Source of Variation	SS	df	MS	F	Sig. (p)	Effect Size (Cohen's d)	Information
Mathematical Problem-Solving Score	Group (IDLT vs Conventional)	982.45	1	982.45	**15.684**	**0.001***	**0.86**	Significant (moderate-high effect)
	Error	7321.78	117	62.58				
	Total	8304.23	119					

Table 2. The above shows that the implementation of Integrated Digital Learning Tools (IDLT) results in a significant improvement in students' mathematical problem-solving abilities. ANCOVA's analysis showed a significant difference between the experimental and control groups (p = 0.001 < 0.05) and large effects (Cohen's d = 0.86). Mathematical thinking skills based on the model of Polya (1945) show that the most notable improvement occurs in three main stages: understanding the problem, executing the plan, and verification. Improvement in the understanding the problem stage is driven by the use of interactive simulations and conceptual visualizations that help students understand abstract representations in concrete terms. Meanwhile, the ability to execute the plan is significantly improved thanks to the adaptive activities and real-time digital feedback provided by the IDLT system, allowing students to tailor their completion strategies based on automated evaluation(Arifin & Efriani, 2025; Anwary, 2023; Dewanto et al., 2023). The ability to verify is strengthened through reflection based on learning analytics, where students can review the steps to solve it and recognize mistakes independently.

These results support the research of Zhao and Ko (2021) and Mishra and Koehler (2006) who emphasized that the balanced integration of technology, content, and pedagogy (TPACK framework) is able to improve reflective thinking processes and metacognitive awareness in digital mathematics learning (Elfira & Santosa, 2023)

4. Kesimpulan

The results of this research can be that the application of Integrated Digital Learning Tools (IDLT) has proven to be effective in significantly improving students' mathematical problem-solving skills. The integration of various interactive simulation digital platforms, adaptive learning systems, and learning analytics is able to strengthen cognitive and metacognitive interactions in each stage of problem solving according to the Polya model, especially in the aspects of understanding the problem, executing the plan, and verification. The improvement of these abilities is supported by real-time digital feedback and data-driven reflection that encourages thinking awareness and independent learning strategies. The high effect size value (Cohen's d = 0.86) showed that IDLT had a strong pedagogical impact on the development of students' higher-order thinking skills (HOTS). Thus, the integration of digital technology that is pedagogically designed is not just a means of learning aid, but is an instrument of learning transformation towards a student-centered learning model that is adaptive, reflective, and relevant to the demands of the Industrial Revolution 4.0 and Society 5.0.

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