IJE
Interdiciplinary Journal of Education
https://skillerindonesia.id/index.php/ije/index

Vol. 4, No 2: July 2026
E-ISSN: 2988-7798
pp. 81-91
Email:ije@skillerindonesia.com

Technology-Integrated Discovery Learning for Elementary Mathematical Understanding and Engagement

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Abstract: This study developed and evaluated a technology-integrated discovery learning model to strengthen elementary students' mathematical conceptual understanding and learning engagement. Although digital technologies are increasingly available in primary classrooms, mathematics instruction frequently remains dominated by teacher-centered practices that prioritize procedural fluency over conceptual reasoning. To address this problem, the study employed a Research and Development design guided by the ADDIE framework, which comprises analysis, design, development, implementation, and evaluation. The participants included fifth-grade elementary students involved in small-group and large-group trials, a classroom teacher, and three expert validators specializing in mathematics education, instructional media, and language. Data were collected using expert validation sheets, teacher and student practicality questionnaires, classroom observations, and pretest-posttest assessments. The data were analyzed through descriptive statistics, normalized gain analysis, and paired-sample t-tests. The findings indicate that the developed model achieved a high level of validity, with an average expert validation score of 90%. Teacher and student responses also showed that the model was highly practical, with an average practicality score of 89%. Furthermore, implementation of the model substantially improved students' mathematics learning outcomes, as reflected in high N-gain scores of 0.81 in the small-group trial and 0.75 in the large-group trial. Paired-sample t-tests confirmed significant differences between pretest and posttest scores ($p < .05$). These findings suggest that integrating discovery learning with digital technology offers a pedagogically sound, student-centered, and conceptually meaningful approach to elementary mathematics instruction.

Article History
Received: 11-02-2026
Revised: 21-05-2026
Published: 20-07-2026

Key Words :
Technology-Integrated Learning; Discovery Learning; Mathematics Education; Conceptual Understanding; Learning Engagement; Elementary Education

How to Cite: Usman, S., Waluyo, E., & Supiati, S. (2026). Technology-Integrated Discovery Learning for Elementary Mathematical Understanding and Engagement. *IJE : Interdisciplinary Journal of Education*, *4*(2), 81–91. https://doi.org/10.61277/ije.v4i2.295

https://doi.org/10.61277/ije.v4i2.295

1. Introduction

Mathematics education in elementary schools is central to the development of logical reasoning, problem-solving ability, and higher-order thinking. Nevertheless, many elementary mathematics classrooms continue to rely on teacher-centered instruction that emphasizes procedural fluency rather than conceptual understanding. In such settings, students tend to memorize formulas and algorithms without developing a sufficiently deep understanding of the mathematical ideas underlying those procedures. This condition may reduce students' engagement, limit meaningful learning, and contribute to persistent difficulties in mathematics achievement.

The need to improve mathematics learning has become increasingly urgent in the context of twenty-first-century education. Contemporary learners are expected not only to acquire disciplinary knowledge but also to develop critical thinking, creativity, collaboration, communication, and digital literacy. International assessment evidence further underscores the importance of strengthening mathematics learning through more adaptive, equitable, and conceptually meaningful instructional practices (OECD, 2023). For elementary learners, such improvement requires instructional models that are developmentally appropriate, cognitively engaging, and capable of connecting abstract mathematical concepts with concrete learning experiences.

Digital technology has considerable potential to support mathematics instruction because it can provide interactive representations, simulations, multimedia resources, immediate feedback, and flexible learning pathways. Meta-analytic evidence shows that technology can positively influence learning achievement when it is integrated into well-designed instructional activities rather than used as an isolated supplement (Hillmayr et al., 2020; Tamim et al., 2011). Its educational value therefore depends on how it is aligned with pedagogy, content, learner characteristics, and classroom interaction. Accordingly, technology integration in mathematics should be embedded within instructional models that encourage exploration, inquiry, reasoning, and student participation.

Discovery learning provides a relevant pedagogical foundation for technology-supported mathematics instruction. Rooted in constructivist learning theory, discovery learning positions students as active constructors of knowledge who investigate problems, collect and process information, verify findings, and formulate conclusions. When appropriately guided, discovery learning can promote deeper conceptual understanding because students are encouraged to make sense of mathematical ideas rather than merely reproduce procedures (Alfieri et al., 2011; Bruner, 1961; Lazonder & Harmsen, 2016; Mayer, 2004).

Despite the growing literature on educational technology and discovery learning, several gaps remain. First, many studies on technology-based instruction focus primarily on digital tools without integrating them into a coherent pedagogical framework. Second, research on discovery learning often emphasizes learning syntax and classroom procedures while giving limited attention to digital technology as a cognitive and representational tool. Third, prior studies have frequently examined learning outcomes and engagement separately, whereas effective elementary mathematics instruction requires simultaneous attention to conceptual understanding and learning engagement.

To address these gaps, this study developed a technology-integrated discovery learning model for elementary mathematics instruction. The model combines constructivist discovery learning stages with interactive digital learning tools and was developed using the ADDIE instructional design framework. This study contributes to the literature by offering a systematically designed and empirically evaluated instructional model that addresses validity, practicality, and effectiveness. Practically, the model is expected to help teachers create more interactive, student-centered, and conceptually rich mathematics learning environments.

Accordingly, this study aims to develop and evaluate a technology-integrated discovery learning model to enhance elementary students' mathematical conceptual understanding and learning engagement. Specifically, the study examines the validity, practicality, and effectiveness of the developed model in elementary mathematics classrooms.

2. Literature Review

2.1 Technology-Enhanced Mathematics Learning

Technology-enhanced mathematics learning refers to the purposeful use of digital tools to support students' exploration, representation, practice, communication, and reflection in mathematics. In elementary education, digital technology can help learners visualize abstract concepts, manipulate mathematical objects, and receive immediate feedback on their reasoning. These affordances are particularly important because mathematical ideas

IJE
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Vol. 4, No 2: July 2026
E-ISSN: 2988-7798
pp. 81-91
Email:ije@skillerindonesia.com

such as fractions, geometry, measurement, and patterns often require visual and interactive representations that are difficult to convey through verbal explanation alone (Hillmayr et al., 2020; Mayer, 2009).

Previous research has shown that technology-supported learning environments can improve students' engagement and academic performance when digital tools are integrated into meaningful learning activities. Tamim et al. (2011), in a second-order meta-analysis, reported a positive overall association between technology use and learning achievement in formal classroom settings. Similarly, Hillmayr et al. (2020) found that digital tools can enhance mathematics and science learning when their use is closely connected to subject-specific instructional design. These findings indicate that technology should be treated not only as a medium for delivering content but also as a learning tool that supports students' mathematical thinking.

2.2 Discovery Learning in Mathematics Education

Discovery learning is a constructivist instructional approach that encourages learners to build knowledge through inquiry, exploration, and guided problem solving. In discovery learning, students are invited to observe phenomena, identify problems, collect information, test ideas, verify conclusions, and formulate generalizations. This process allows students to participate actively in knowledge construction rather than passively receiving explanations from teachers.

In mathematics education, discovery learning is particularly relevant because conceptual understanding requires students to identify relationships among mathematical ideas, explain patterns, justify strategies, and apply concepts in new contexts. Bruner (1961) argued that discovery learning can strengthen intellectual development because learners organize and transform information through active inquiry. However, unassisted discovery may place excessive cognitive demands on students; therefore, guided discovery supported by scaffolding, feedback, worked examples, and teacher facilitation is more likely to improve learning outcomes and conceptual understanding (Alfieri et al., 2011; Lazonder & Harmsen, 2016; Mayer, 2004).

2.3 Integrating Technology and Discovery Learning

The integration of technology and discovery learning is grounded in the view that digital tools can enrich inquiry-based learning by providing representations, simulations, interactive tasks, and collaborative spaces. Technology can support the stimulation stage by presenting meaningful problems, assist data collection through digital worksheets or online resources, facilitate data processing through visual representations, and support verification through feedback and reflection activities. In this way, technology becomes part of the cognitive architecture of learning rather than an external accessory to instruction.

Effective technology integration requires pedagogical coherence. Tondeur et al. (2020) emphasized that meaningful technology use depends on teachers' ability to align digital tools with student-centered pedagogy and technological pedagogical content knowledge. Broader meta-analytic evidence also indicates that technology has stronger effects when it is embedded in deliberate instructional design rather than added as a peripheral resource (Tamim et al., 2011). Therefore, combining technology with discovery learning may strengthen students' engagement and understanding when digital tools are intentionally used to support exploration, discussion, verification, and conceptual generalization.

2.4 Conceptual Understanding and Learning Engagement

Mathematical conceptual understanding refers to students' ability to comprehend mathematical meanings, explain relationships among concepts, apply concepts flexibly, and justify problem-solving strategies. It differs from procedural competence because it requires students to understand why a mathematical method works, not merely how to apply it. In elementary mathematics, conceptual understanding is a foundation for later mathematical reasoning, problem solving, and transfer of knowledge, and it develops iteratively with procedural skill through meaningful problem representation and reflection (Rittle-Johnson et al., 2001).

Learning engagement refers to students' behavioral, emotional, and cognitive involvement in learning. Behaviorally engaged students participate in activities, ask questions, and complete tasks; emotionally engaged students show interest, confidence, and enjoyment; and cognitively engaged students invest effort in

Vol. 4, No 2: July 2026
E-ISSN: 2988-7798
pp. 81-91
Email:ije@skillerindonesia.com

understanding, reasoning, and solving problems (Fredricks et al., 2004). The ICAP framework further suggests that learning becomes deeper when students move from passive reception toward active, constructive, and interactive engagement (Chi & Wylie, 2014). Technology-integrated discovery learning is therefore expected to support these dimensions of engagement by providing interactive tasks, collaborative exploration, and opportunities for students to construct and communicate mathematical ideas.

3. Research Method

This study employed a Research and Development (R&D) design to develop and evaluate a technology-integrated discovery learning model for elementary mathematics instruction. The development process followed the ADDIE framework, which consists of five systematic stages: analysis, design, development, implementation, and evaluation. The ADDIE framework was selected because it offers a structured and iterative process for producing instructional products that are pedagogically valid, practically feasible, and empirically testable (Branch, 2009). The study also followed the logic of educational design research, which emphasizes the development and evaluation of practical solutions to educational problems through systematic inquiry (Plomp, 2013; Reeves, 2006).

The research was conducted during the 2025 academic year at an elementary school in Indonesia. The participants consisted of fifth-grade elementary students, one classroom teacher, and three expert validators. Participants were selected using purposive sampling because they were directly relevant to the objectives of the study. The small-group trial involved 15 students and was conducted to identify initial weaknesses, usability issues, and implementation challenges. The large-group trial involved 32 students and was conducted to examine the effectiveness of the model in a more authentic classroom setting. The validation process involved a mathematics education expert, an instructional media expert, and a language expert.

During the analysis stage, classroom observations, teacher interviews, and preliminary assessments were conducted to identify instructional problems, students' learning characteristics, curriculum requirements, and classroom needs. The findings indicated that mathematics instruction was still largely teacher-centered, students had difficulty explaining mathematical concepts, and digital technology was used mainly for presentation rather than inquiry-based learning. These findings informed the design of the instructional model.

During the design stage, learning objectives, instructional syntax, digital activities, assessment procedures, and learning resources were systematically formulated. The model incorporated six guided discovery phases: stimulation, problem identification, data collection, data processing, verification, and generalization. Digital tools, including multimedia presentations, educational videos, digital worksheets, and online learning activities, were mapped onto these phases to support exploration, representation, collaboration, and reflection.

During the development stage, lesson plans, teaching materials, digital media, student worksheets, validation sheets, practicality questionnaires, and pretest-posttest instruments were produced. The developed products were evaluated by the expert validators in terms of content relevance, instructional design quality, media appropriateness, language clarity, and technology integration. Revisions were made based on expert suggestions before classroom implementation.

The implementation stage consisted of small-group and large-group trials. In both trials, students participated in technology-supported discovery learning activities designed to promote active exploration, collaborative problem solving, and conceptual understanding. The teacher served as a facilitator who guided inquiry, provided scaffolding, encouraged discussion, and supported students in formulating mathematical conclusions. Pretest and posttest assessments were administered before and after implementation to examine students' learning improvement.

The study used both test and non-test instruments. The non-test instruments consisted of expert validation sheets, teacher practicality questionnaires, student practicality questionnaires, and classroom observation notes. The test instruments consisted of pretest and posttest assessments developed based on elementary mathematics

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curriculum indicators and designed to measure students' conceptual understanding and problem-solving ability. Content validity was established through expert judgment, while instrument reliability was assessed using Cronbach's alpha. All instruments obtained reliability coefficients above 0.80, indicating adequate internal consistency for educational research (Creswell & Creswell, 2018).

The data were analyzed using descriptive and inferential statistical techniques. Validation and practicality data were analyzed using percentage-based descriptive statistics. The effectiveness of the model was analyzed using normalized gain (N-gain) and paired-sample t-tests. N-gain was used to estimate the magnitude of learning improvement from pretest to posttest. Mean N-gain values were categorized as high ($g > 0.70$), moderate ($0.30 <= g <= 0.70$), and low ($g < 0.30$). Paired-sample t-tests were conducted to determine whether pretest-posttest differences were statistically significant at the .05 level.

Ethical principles were observed throughout the study. Permission was obtained from the school administration before data collection. Participation was voluntary, and informed consent was obtained from the teacher and students involved in the study. The anonymity and confidentiality of all participants were maintained, and the collected data were used only for research purposes.

4. Results and Discussion

4.1 Results

The findings are presented according to the three quality criteria of the developed instructional model: validity, practicality, and effectiveness. Validity was examined through expert judgment, practicality was evaluated using teacher and student responses, and effectiveness was assessed through students' pretest and posttest performance during the implementation trials.

4.1.1 Expert Validation Results

The first stage of analysis evaluated the validity and feasibility of the developed technology-integrated discovery learning model. The expert validators assessed the model based on material relevance, media quality, language clarity, and the suitability of technology integration. As shown in Table 1, the material aspect obtained a score of 92%, the media aspect obtained 90%, and the language aspect obtained 88%. The average validation score was 90%, which falls within the very valid category.

These results indicate that the developed model was theoretically appropriate, instructionally feasible, and suitable for classroom trials. The validators also recommended improving the clarity of several student instructions, refining the visual consistency of the digital media, and simplifying some mathematical explanations to better match elementary students' cognitive development. These recommendations were incorporated before implementation.

Table 1. Expert Validation Results

Validation Aspect	Percentage (%)	Category
Material validation	92	Very valid
Media validation	90	Very valid
Language validation	88	Very valid
Average	**90**	**Very valid**

4.1.2 Practicality Results

The practicality of the developed model was evaluated based on teacher and student responses after the implementation stage. The practicality assessment focused on ease of use, clarity of instructional procedures, attractiveness of learning activities, usefulness of digital learning tools, and the overall learning experience.

The findings show that both students and the teacher responded positively to the implementation of the technology-integrated discovery learning model. As presented in Table 2, student responses reached 88%, while the teacher response reached 91%. The average practicality score was 89%, which is categorized as very practical.

The high practicality scores indicate that the model was easy to implement and capable of creating an engaging learning environment. Students reported that the integration of interactive digital media made mathematics learning more interesting, enjoyable, and easier to understand. The teacher also perceived that the instructional syntax provided a clear structure for facilitating active learning and encouraging student participation. Classroom observations further showed that students participated actively in discussions, explored mathematical problems collaboratively, and used digital learning tools effectively during the discovery learning process.

Table 2. Teacher and Student Practicality Responses

Respondent	Percentage (%)	Category
Students	88	Very practical
Teacher	91	Very practical
Average	**89**	**Very practical**

4.1.3 Effectiveness Results

The effectiveness of the developed instructional model was evaluated using pretest and posttest assessments administered during the small-group and large-group trials. The assessments measured students' improvement in mathematical conceptual understanding after participating in technology-supported discovery learning activities.

The results demonstrate substantial improvement in students' mathematics learning outcomes after the implementation of the developed model. As presented in Table 3, the small-group trial showed an increase in the mean score from 55 in the pretest to 90 in the posttest, producing an N-gain score of 0.81, which is categorized as high. Similarly, the large-group trial showed an increase from 58 in the pretest to 88 in the posttest, with an N-gain score of 0.75, also categorized as high.

The high N-gain scores indicate that the technology-integrated discovery learning model was effective in improving students' mathematical conceptual understanding. The findings suggest that digital technology, when embedded within discovery learning activities, can facilitate meaningful learning experiences and support students in actively constructing mathematical concepts.

To further examine effectiveness, paired-sample t-tests were conducted to compare students' pretest and posttest scores. The analysis revealed statistically significant differences between pretest and posttest scores in both implementation stages ($p < .05$), indicating that the improvement in students' mathematics learning outcomes was statistically meaningful after the model was implemented.

The improvement in learning outcomes was also reflected in classroom learning behavior. During implementation, students demonstrated increased participation, collaborative interaction, and problem-solving engagement. They were actively involved in identifying mathematical problems, collecting information, analyzing findings, and drawing conclusions through guided discovery activities supported by interactive digital media.

Table 3. Improvement of Students' Mathematics Learning Outcomes

Group	Pretest Mean	Posttest Mean	N-Gain	Category
Small group	55	90	0.81	High
Large group	58	88	0.75	High

Overall, the results demonstrate that the developed technology-integrated discovery learning model fulfilled the three primary criteria of educational product quality: validity, practicality, and effectiveness. These findings confirm that integrating constructivist discovery learning principles with digital learning technologies can enhance elementary students' mathematical conceptual understanding and learning engagement.

IJE
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Vol. 4, No 2: July 2026
E-ISSN: 2988-7798
pp. 81-91
Email:ije@skillerindonesia.com

4.2 Discussion

The findings of this study demonstrate that the technology-integrated discovery learning model significantly improved elementary students' mathematical conceptual understanding and learning engagement. The developed model fulfilled the three essential criteria of educational product quality: validity, practicality, and effectiveness. The high validation scores indicate that the model was theoretically sound, instructionally appropriate, and pedagogically feasible for elementary mathematics classrooms. In addition, positive teacher and student responses show that the model was practical and capable of creating engaging, interactive, and student-centered learning experiences. These outcomes are consistent with the logic of educational design research, which emphasizes the iterative development and evaluation of solutions that are valid, usable, and effective in authentic educational settings (Branch, 2009; Plomp, 2013; Reeves, 2006).

A key finding of this study is the substantial improvement in students' mathematics learning outcomes after implementation. The high N-gain scores obtained in both the small-group and large-group trials indicate that the integration of discovery learning and digital technology effectively supported conceptual understanding and active knowledge construction. This finding is consistent with constructivist learning theory, which emphasizes that meaningful learning occurs when students actively construct understanding through exploration, inquiry, and interaction rather than passively receiving information from teachers. Bruner (1961) argued that discovery learning enables learners to organize and transform information independently, thereby supporting deeper cognitive processing and longer-term conceptual retention.

The improvement in learning outcomes may be explained by several interconnected instructional factors embedded in the model. First, the discovery learning process encouraged students to identify problems, collect information, analyze data, and formulate conclusions. These activities stimulated higher-order thinking processes, including analysis, evaluation, reasoning, and generalization. Such processes are essential for conceptual mathematics learning because students must understand relationships among mathematical ideas rather than simply memorize procedures. This interpretation is consistent with evidence showing that guided discovery and inquiry-based learning supported by scaffolding can enhance students' problem-solving ability and conceptual comprehension (Alfieri et al., 2011; Lazonder & Harmsen, 2016; Mayer, 2004).

Second, digital technology contributed to student engagement and conceptual visualization. Interactive multimedia, digital worksheets, and technology-supported activities enabled students to explore mathematical ideas more dynamically and visually. This finding aligns with research indicating that technology-enhanced learning environments can improve student participation, motivation, and conceptual understanding when digital tools are integrated into learner-centered instructional designs (Hillmayr et al., 2020; Tamim et al., 2011). Multimedia-based learning environments can also reduce conceptual difficulty by helping students process abstract mathematical relationships through visual and verbal representations (Mayer, 2009).

The findings further indicate that technology integration alone is insufficient unless supported by a coherent pedagogical framework. In conventional classrooms, technology is often used only to display information, which does not necessarily transform the learning process. In contrast, the present model integrated digital tools directly into the stages of discovery learning, allowing technology to function as a cognitive support for exploration, inquiry, verification, and collaborative problem solving. This finding supports the view that meaningful technology integration requires student-centered pedagogy, teacher readiness, and deliberate instructional design (Tamim et al., 2011; Tondeur et al., 2020).

Another important finding concerns the high level of student engagement observed during classroom implementation. Students showed greater participation, enthusiasm, and collaborative interaction throughout the learning activities. This suggests that the combination of digital technology and discovery learning can create more engaging learning experiences than conventional teacher-centered approaches. Previous research similarly indicates that technology-supported learning environments can strengthen behavioral, emotional, and cognitive engagement by encouraging students to interact with learning materials, peers, and teachers (Bond et al., 2020;

Fredricks et al., 2004). The emphasis on discussion, explanation, and collaborative verification in the present model is also consistent with the ICAP framework, which views constructive and interactive engagement as conditions that support deeper learning (Chi & Wylie, 2014).

From a pedagogical perspective, the model successfully shifted classroom learning from passive knowledge transmission to active knowledge construction. Students were not positioned merely as recipients of information but as active participants who explored, discussed, tested, and generalized mathematical ideas. This shift is especially important in elementary mathematics, where misconceptions may develop when instruction is dominated by memorization and procedural practice. By integrating digital representations into guided discovery activities, the model provided opportunities for students to develop both conceptual clarity and learning confidence, thereby supporting the iterative relationship between conceptual and procedural knowledge (Rittle-Johnson et al., 2001).

The study also contributes theoretically by extending previous research on discovery learning and educational technology integration. While earlier studies often examined discovery learning and digital learning separately, this study developed and empirically evaluated an integrated instructional framework for elementary mathematics education. The findings reinforce the importance of aligning technological integration with constructivist pedagogy to optimize learning effectiveness (Alfieri et al., 2011; Hillmayr et al., 2020; Lazonder & Harmsen, 2016). They also provide practical evidence that technology-enhanced discovery learning can be implemented in elementary school contexts when supported by clear instructional syntax, appropriate digital resources, and teacher facilitation.

Despite these contributions, several limitations should be acknowledged. The study was conducted in a limited educational context with a relatively small number of participants, which may restrict the generalizability of the findings. In addition, the implementation focused primarily on short-term learning outcomes rather than long-term conceptual retention or transfer of mathematical understanding. The study also emphasized conceptual understanding and engagement, while other important variables such as self-regulated learning, creativity, digital literacy, and collaborative problem-solving skills were not examined comprehensively.

Future studies should involve larger and more diverse participant groups across different grade levels and educational contexts. Longitudinal research is also needed to examine the long-term effects of technology-integrated discovery learning on conceptual retention, mathematical reasoning, and higher-order thinking. Further research may also investigate how teacher digital competence, instructional readiness, and technological accessibility influence the effectiveness of technology-enhanced discovery learning environments.

5. Conclusion

This study developed and evaluated a technology-integrated discovery learning model designed to enhance elementary students' mathematical conceptual understanding and learning engagement. The findings demonstrate that the developed instructional model fulfilled the three primary criteria of educational product quality: validity, practicality, and effectiveness. Expert validation confirmed that the model was pedagogically appropriate, theoretically grounded, and feasible for classroom implementation. Teacher and student responses also indicated that the model was highly practical and capable of creating engaging and interactive mathematics learning experiences.

The implementation of the model significantly improved students' mathematics learning outcomes, as reflected in the high N-gain scores obtained in both the small-group and large-group trials. These findings suggest that integrating discovery learning principles with digital learning technologies can promote active participation, conceptual understanding, collaborative interaction, and meaningful learning experiences. The study further demonstrates that digital technology can function not merely as an instructional medium but also as a cognitive tool that supports inquiry, exploration, visualization, and higher-order thinking in mathematics learning.

IJE
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E-ISSN: 2988-7798
pp. 81-91
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From a theoretical perspective, the study contributes to constructivist and technology-enhanced learning literature by proposing and empirically validating an instructional framework that integrates discovery learning pedagogy with digital instructional design. Unlike studies that examine discovery learning and educational technology separately, this study provides an integrated model that combines both approaches within elementary mathematics education. The findings therefore reinforce the importance of aligning technological integration with student-centered pedagogy to optimize learning effectiveness.

From a practical perspective, the developed model offers an applicable instructional framework for teachers who seek to implement more interactive, student-centered, and technology-supported mathematics instruction. The study also highlights the importance of adequate technological infrastructure, teacher digital competence, and pedagogical readiness in supporting effective classroom implementation. Overall, the technology-integrated discovery learning model represents an innovative and effective instructional approach for improving elementary students' mathematical conceptual understanding and learning engagement in the digital era.

6. Recommendation

Based on the findings of this study, several recommendations are proposed for teachers, schools, policymakers, and future researchers. First, elementary school teachers are encouraged to implement technology-integrated discovery learning as an alternative instructional approach for strengthening students' mathematical conceptual understanding and learning engagement. Teachers should optimize the use of digital learning tools, such as interactive multimedia, digital worksheets, educational videos, and online learning platforms, to support inquiry-based and student-centered learning activities. They should also facilitate collaborative learning environments that encourage students to explore, discuss, and construct mathematical concepts actively.

Second, schools and educational institutions should provide adequate technological infrastructure and continuous professional development programs to support the successful implementation of technology-enhanced learning models. Access to digital devices, stable internet connectivity, and appropriate learning platforms is essential for optimizing technology-supported instruction. Schools should also organize training programs that improve teachers' digital literacy, pedagogical competence, and instructional design skills.

Third, educational policymakers are encouraged to promote technology-supported constructivist learning approaches within elementary education curricula. Policies on digital transformation in education should not focus solely on technological availability but should also emphasize pedagogical innovation and student-centered instructional practices. Curriculum developers should therefore consider integrating discovery-oriented and technology-enhanced learning models into mathematics education frameworks to support the development of twenty-first-century competencies.

Finally, future researchers are encouraged to conduct studies involving larger and more diverse participant groups across different educational levels and contexts. Future research may examine the long-term effects of technology-integrated discovery learning on conceptual retention, higher-order thinking, self-regulated learning, creativity, digital literacy, and collaborative problem solving. Additional studies examining teacher readiness, digital competence, and technological accessibility would also provide valuable insights for improving technology-enhanced mathematics instruction.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available because they contain information related to student participants and are subject to institutional and ethical confidentiality requirements.

Declaration of the use of artificial intelligence (AI)

The authors declare that artificial intelligence-assisted tools were used only to support language refinement, grammar checking, sentence clarity, and academic style improvement during manuscript preparation. AI tools were not used to generate research data, conduct statistical analysis, interpret the findings, or draw scientific conclusions. All intellectual content, research design, data analysis, interpretation, and final conclusions remain the full responsibility of the authors. The authors have reviewed, verified, and approved the final version of the manuscript.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. The study was conducted independently by the authors as part of their academic and research activities.

Acknowledgment

The authors express their sincere gratitude to all individuals and institutions that contributed to the completion of this study. Special appreciation is extended to the lecturers and academic supervisors of the Department of Primary Education, Universitas Hamzanwadi, for their valuable guidance, constructive feedback, and continuous academic support throughout the research process.

The authors also thank the school principal, teacher, and fifth-grade students who participated in this study for their cooperation, enthusiasm, and active involvement during the research implementation. Their support contributed substantially to the successful completion of this study.

The authors further acknowledge the expert validators for their insightful suggestions and professional evaluations, which significantly improved the quality of the developed instructional model and research instruments.

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