



A data-informed decision framework for geogebra-supported learning: Enhancing students' conceptual understanding and self-efficacy

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Article Information	Abstract
Submitted: Jan 17, 2026 Revised: March 23, 2026 Accepted: April 05, 2026 Keywords Data-informed learning; Decision sciences; GeoGebra-supported learning; Human learning; Self-efficacy.	Purpose: This study aims to examine how data-informed instructional decisions supported by GeoGebra influence students' mathematical conceptual understanding and self-efficacy within a technology-enhanced learning environment. Method: A factorial experimental design was employed involving eleventh-grade students selected through cluster random sampling. The experimental group received GeoGebra-supported direct instruction, while the control group experienced conventional learning. Data were collected through pretest–posttest measures of conceptual understanding, self-efficacy questionnaires, and classroom observations. The data were analyzed using two-way ANOVA to determine the effects of instructional approach and self-efficacy levels. Findings: The results indicate that students exposed to GeoGebra-supported instruction achieved significantly higher conceptual understanding compared to those in conventional settings. Self-efficacy also showed a significant effect on learning outcomes, while no significant interaction was found between instructional approach and self-efficacy. Significance: This study contributes to decision sciences in human learning by highlighting the role of instructional design decisions and learners' belief systems in shaping learning outcomes. The findings support the development of data-informed and human-centered decision frameworks in technology-enhanced learning environments.

INTRODUCTION

The expansion of digital technology has progressively reshaped how human learning occurs across formal, non-formal, and informal environments. Learning is no longer restricted to classroom interactions but increasingly unfolds through digitally mediated experiences that allow flexibility, interactivity, and personalization (Alam & Mohanty, 2023; Grimaldi & Ball, 2021; Rambe & Bere, 2013). In the context of mathematics education, this shift is particularly significant because abstract concepts often require visual and dynamic representations to be meaningfully understood (Alam & Mohanty, 2024; Shvarts & Abrahamson, 2023; Žakelj & Klančar, 2022). Digital tools, therefore, function not merely as instructional aids but as environments where learners actively construct knowledge (Mhlongo et al., 2023; Reinhold et al., 2024). This transformation has encouraged a gradual movement away from transmissive teaching toward more learner-responsive approaches (Chitra1 & Gunasekaran, 2025). However, the effectiveness of such environments depends not only on the availability of technology but also on how learning experiences are intentionally structured. For this reason, examining the role of instructional decision-making within technology-enhanced learning contexts becomes increasingly essential.

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Despite these advancements, improving students' conceptual understanding in mathematics continues to be a persistent challenge. Many students encounter difficulties in connecting symbolic representations, interpreting relationships among concepts, and applying their knowledge in unfamiliar contexts (Post & Prediger, 2024; Tondorf & Prediger, 2022). Such difficulties are often associated with instructional practices that emphasize procedural fluency at the expense of conceptual reasoning (Lee, 2025; Schulz, 2024). As a result, students may succeed in performing calculations while lacking a deeper understanding of underlying principles (Pursnani et al., 2023; Tsai et al., 2023). Previous studies have also indicated that exposure to varied teaching methods does not automatically guarantee meaningful learning if the instructional design is not aligned with learners' needs (Abuhassna & Alnawajha, 2023; Zhang et al., 2022). This suggests that the issue lies not only in what is taught but also in how instructional decisions are made. Therefore, there is a need to reconsider instructional approaches by focusing on how they support conceptual understanding more effectively.

In response to these challenges, dynamic mathematics software such as GeoGebra has emerged as a promising tool to support conceptual learning. GeoGebra enables learners to explore mathematical ideas through interactive visualization, linking algebraic, graphical, and geometric representations in a coherent manner (Ziatdinov & Valles, 2022). Through this interactive process, students are provided with opportunities to manipulate objects and observe patterns, which can enhance their conceptual insights (Panjaitan et al., 2025). Empirical evidence suggests that the integration of GeoGebra can increase both engagement and achievement in mathematics learning (Hidayat, et al., 2023). Nevertheless, the effectiveness of such tools is highly contingent upon how they are embedded within instructional practices. Technology alone does not determine learning outcomes; rather, it is the pedagogical decisions surrounding its use that shape its impact (Dilek et al., 2025; Nguyen, 2025). Accordingly, it becomes necessary to investigate how GeoGebra-supported instruction can be systematically designed to enhance conceptual understanding.

Beyond instructional design, students' internal characteristics also play a significant role in shaping learning processes, particularly their level of self-efficacy. Self-efficacy refers to an individual's belief in their capability to perform tasks successfully and has been widely recognized as a key factor influencing learning behavior (Meng & Zhang, 2023). In mathematics contexts, students with higher self-efficacy are more likely to engage persistently with challenging problems and adopt effective learning strategies (Zakariya, 2022; Zuo et al., 2024). Conversely, students with lower self-efficacy tend to avoid complex tasks and demonstrate reduced effort (Feldon et al., 2024). A substantial body of research has confirmed the positive relationship between self-efficacy and academic performance (Al-Abyadh & Abdel Azeem, 2022; Zhao et al., 2024). However, the interaction between self-efficacy and technology-supported instruction remains insufficiently explored. In particular, it is still unclear how learners' beliefs interact with instructional decisions in shaping learning outcomes. This highlights the importance of examining self-efficacy within a broader instructional and contextual framework.

From the perspective of decision sciences, learning can be interpreted as the outcome of a series of interconnected decisions made by both teachers and learners. Teachers make decisions regarding instructional strategies, the selection of technological tools, and the

structuring of learning activities. From the perspective of decision sciences, learning can be interpreted as the outcome of a series of tasks, allocate effort, and persist in the face of difficulty. These decision processes are influenced by external conditions, such as instructional design, as well as internal factors, including self-efficacy and motivation (Gigerenzer & Gaissmaier, 2011). In digitally mediated environments, the complexity of these decisions increases due to the availability of multiple learning pathways and resources (Siemens, 2013). Despite its relevance, the application of decision sciences frameworks in mathematics education research remains relatively limited. Most existing studies emphasize learning outcomes without explicitly addressing the decision-making processes that lead to those outcomes. This gap underscores the need for a more integrative perspective that connects instructional design, learner characteristics, and decision-making dynamics.

Based on these considerations, this study aims to investigate how GeoGebra-supported instruction influences students' conceptual understanding and self-efficacy within a data-informed decision framework. Specifically, the study examines the effects of instructional approaches and varying levels of self-efficacy using a factorial experimental design. By integrating technological, cognitive, and decision-oriented perspectives, this research seeks to provide a more comprehensive account of learning processes. The study positions instructional practices as part of a broader system of decision-making that shapes learning outcomes. In addition, it highlights the role of learners' internal beliefs in mediating their responses to instructional interventions. The findings are expected to offer insights for designing more adaptive and effective learning environments. Ultimately, this research contributes to the advancement of decision sciences in the context of human learning and development.

LITERATURE REVIEW

Conceptual understanding is widely regarded as a fundamental goal in mathematics education, as it enables learners to grasp underlying principles rather than merely perform procedural operations. It involves the ability to connect mathematical ideas, interpret representations, and apply knowledge in various contexts (Hiebert & Lefevre, 1986; Rittle-Johnson et al., 2017). Students with strong conceptual understanding are more capable of transferring knowledge and solving non-routine problems effectively (Kilpatrick et al., 2001). However, developing such understanding remains a challenge, particularly when instruction prioritizes procedural fluency over meaning-making (Star et al., 2015). Previous research indicates that conceptual understanding is best supported through interactive and exploratory learning environments that allow students to actively construct knowledge (Schoenfeld, 2016). This suggests that instructional design plays a crucial role in facilitating meaningful learning. Therefore, identifying instructional approaches that support conceptual understanding becomes a key concern in mathematics education research.

Technology-enhanced learning environments have been increasingly recognized for their potential to support conceptual understanding, particularly through visualization and interaction. GeoGebra, as a dynamic mathematics software, provides an integrated platform that links algebraic, graphical, and geometric representations (Hohenwarter &

Fuchs, 2004). This integration enables learners to explore mathematical relationships dynamically and develop deeper insights (Zengin et al., 2012). Several studies have shown that the use of GeoGebra can improve students' engagement and learning outcomes in mathematics (Arbain & Shukor, 2015; Buteau et al., 2014). Nevertheless, the effectiveness of such tools is not determined solely by their technological features but also by how they are implemented in instructional contexts (Mayer, 2009). In other words, the impact of GeoGebra depends on the quality of instructional decisions guiding its use. This highlights the importance of examining technology integration from a pedagogical and decision-oriented perspective.

Self-efficacy has been identified as a critical psychological factor influencing students' learning behavior and academic performance. According to Bandura (1997), self-efficacy reflects individuals' beliefs in their capability to organize and execute actions required to achieve specific outcomes. In educational contexts, students with higher self-efficacy tend to demonstrate greater persistence, motivation, and strategic behavior (Zimmerman, 2000). Conversely, low self-efficacy is often associated with avoidance and reduced engagement (Schunk & DiBenedetto, 2020). Empirical evidence consistently supports the positive relationship between self-efficacy and academic achievement (Honicke & Broadbent, 2016). However, self-efficacy does not operate in isolation; it interacts with instructional conditions and learning environments. In technology-enhanced settings, students' confidence in using tools and engaging with tasks may influence how they make learning decisions. Therefore, understanding self-efficacy as part of a broader learning system becomes essential.

Decision sciences provide a theoretical lens for understanding how individuals make choices under various conditions, including educational contexts. In learning environments, both teachers and students continuously engage in decision-making processes, ranging from selecting instructional strategies to determining how to approach tasks (Simon, 1977; Shavelson, 1973). These decisions are influenced by multiple factors, including available information, cognitive limitations, and individual beliefs (Gigerenzer & Gaissmaier, 2011). In recent years, the concept of data-informed decision-making has gained attention in education, particularly with the rise of learning analytics and digital technologies (Siemens, 2013). This perspective emphasizes the use of data to guide instructional design and improve learning outcomes. However, existing studies rarely integrate decision sciences with psychological constructs such as self-efficacy. As a result, there is a lack of comprehensive models that explain how instructional decisions and learner characteristics jointly influence learning outcomes.

This study proposes a conceptual framework that positions learning as a decision-driven process influenced by both instructional and individual factors. In this framework, instructional design supported by GeoGebra represents external decision structures that guide how learning experiences are organized. At the same time, self-efficacy functions as an internal factor that shapes learners' decisions in engaging with tasks and persisting in problem-solving activities. These decision processes ultimately influence students' conceptual understanding as a learning outcome. By integrating these components, the framework provides a holistic view of how learning is shaped by the interaction between external instructional decisions and internal learner characteristics. This approach

extends traditional perspectives by explicitly incorporating decision-making as a central mechanism in learning processes.

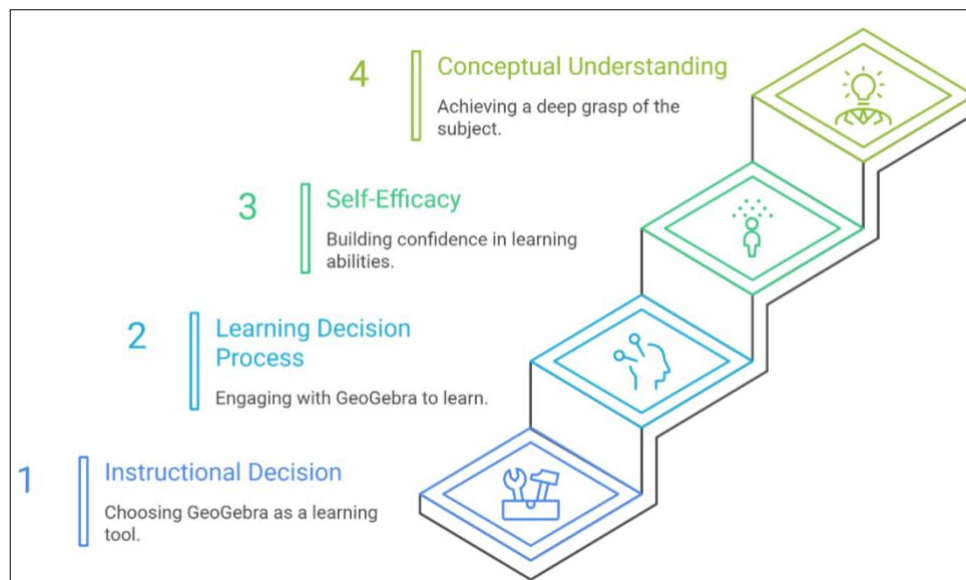


Figure 1. Achieving Conceptual Understanding

METHOD

Research Design

This study employed a factorial experimental design to examine how instructional decisions and learner characteristics influence students' conceptual understanding within a technology-enhanced learning environment. The research adopted a quasi-experimental approach with a pretest–posttest control group design, allowing for the comparison of learning outcomes under different instructional conditions. In this context, the use of GeoGebra-supported direct instruction represents a structured instructional decision aimed at optimizing learning processes. Meanwhile, students' self-efficacy is positioned as an internal factor that influences how learners respond to instructional decisions. The factorial design enables the examination of both main effects and interaction effects between instructional approach and levels of self-efficacy. This design is particularly suitable for capturing the complexity of learning as a decision-driven process involving both external and internal variables. Thus, the research framework integrates experimental methodology with a decision-oriented perspective on learning.

Participants

The participants of this study were eleventh-grade students from a vocational high school in Pekanbaru, Indonesia, during the 2019/2020 academic year. The population consisted of all students enrolled in the relevant grade level, from which two classes were selected using cluster random sampling. One class was assigned as the experimental group, receiving GeoGebra-supported instruction, while the other served as the control group, receiving conventional instruction. This sampling technique was used to ensure representativeness while maintaining the natural classroom structure. From a decision sciences perspective, the selection of participants reflects real-world educational settings where instructional decisions are applied to intact groups rather than randomly assigned individuals. This approach enhances the ecological validity of the study. Therefore, the

participant selection aligns with both experimental rigor and practical educational contexts.

Instruments

Data were collected using multiple instruments designed to capture both learning outcomes and learner characteristics. Students' conceptual understanding was measured through a set of pretest and posttest items developed based on indicators of mathematical concept comprehension. Self-efficacy was assessed using a structured questionnaire that categorizes students into high, medium, and low levels. In addition, observation sheets were used to document instructional implementation and student engagement during the learning process. These instruments were validated to ensure their reliability and appropriateness for the research objectives. From a decision-oriented perspective, the combination of cognitive and psychological measures allows for a more comprehensive understanding of learning processes. The instruments not only capture outcomes but also reflect the internal and external factors that influence learning decisions. Thus, the data collection approach supports the analysis of learning as a multidimensional system.

Procedure

The research procedure consisted of several stages, including preparation, implementation, and evaluation. In the preparation stage, instructional materials and research instruments were developed and validated. During the implementation stage, the experimental group received instruction using GeoGebra as a technological tool integrated into direct instruction, while the control group followed conventional teaching methods. Both groups were given a pretest before the intervention and a posttest after the learning process to measure changes in conceptual understanding. The use of GeoGebra in the experimental group was designed as a deliberate instructional decision to enhance visualization and interaction in learning. Throughout the process, classroom observations were conducted to ensure the consistency of instructional implementation. This procedure reflects how instructional decisions are enacted in real classroom settings. Therefore, the research procedure captures both the planned and enacted dimensions of instructional decision-making. The overall research procedure, which integrates instructional decisions and learner-related factors within a data-informed framework, is illustrated in Figure 2.

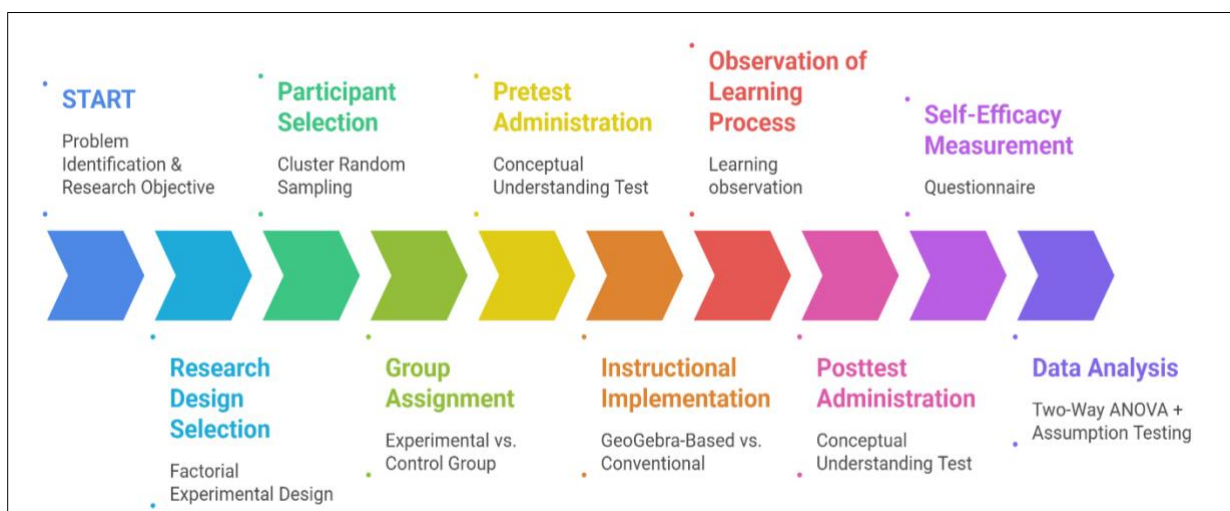


Figure 2. Research Procedure Flowchart

Data Analysis

The collected data were analyzed using two-way analysis of variance (ANOVA) to examine the effects of instructional approach and self-efficacy levels on students' conceptual understanding. Prior to hypothesis testing, prerequisite tests including normality and homogeneity were conducted to ensure the validity of the analysis. The two-way ANOVA allows for the identification of main effects as well as interaction effects between variables. In this study, the instructional approach represents an external decision factor, while self-efficacy represents an internal decision-related characteristic. The analysis, therefore, provides insights into how these factors independently and jointly influence learning outcomes. From a decision sciences perspective, this analytical approach enables the evaluation of how different decision conditions shape performance. Thus, the data analysis not only tests statistical relationships but also interprets learning outcomes within a decision-oriented framework.

RESULTS AND DISCUSSION

Result

The instructional process was implemented in two groups with distinct instructional approaches. The experimental group received GeoGebra-supported direct instruction, while the control group experienced conventional learning. Observational findings indicated that the experimental group demonstrated more active engagement, particularly in exploring mathematical representations through visualization. In contrast, the control group relied more on procedural explanations delivered by the teacher. This difference reflects how instructional decisions shape the structure and dynamics of learning environments. From a decision-oriented perspective, the integration of GeoGebra represents a deliberate instructional strategy aimed at enhancing conceptual engagement. Therefore, the implementation phase confirms that the two groups experienced different learning conditions influenced by instructional design decisions.

The descriptive analysis of students' conceptual understanding is presented in Table 1. Both groups showed improvement from pretest to posttest; however, the increase was more substantial in the experimental group. Students who learned through GeoGebra-supported instruction achieved higher posttest scores compared to those in the conventional group. This indicates that dynamic visualization tools contribute to deeper conceptual understanding by enabling students to connect multiple representations. In contrast, the control group showed a more moderate improvement, suggesting limited opportunities for interactive exploration. These findings provide initial evidence that instructional decisions involving technology integration can enhance learning outcomes.

Table 1. Descriptive Statistics of Conceptual Understanding

Group	N	Pretest Mean	Posttest Mean	Gain	SD
Experimental (GeoGebra)	30	55.20	78.60	23.40	8.15
Control (Conventional)	30	54.80	68.10	13.30	7.92

Further analysis was conducted to examine students' conceptual understanding based on their self-efficacy levels. As shown in Table 2, students with high self-efficacy achieved the highest mean scores, followed by those with moderate and low levels. This pattern indicates that self-efficacy is positively associated with students' ability to understand mathematical concepts. Students with higher self-efficacy demonstrated greater persistence and confidence in solving problems, which contributed to better performance. Conversely, students with lower self-efficacy showed lower engagement and achievement. From a decision sciences perspective, this finding suggests that self-efficacy influences how learners make decisions when engaging with learning tasks. Therefore, self-efficacy can be considered a key internal factor affecting learning outcomes.

Table 2. Conceptual Understanding Based on Self-Efficacy Levels

Self-Efficacy Level	N	Mean Score	SD
High	20	80.25	6.85
Medium	20	72.10	7.40
Low	20	64.35	8.20

To examine the effects of instructional approach and self-efficacy on conceptual understanding, a two-way ANOVA was conducted. The results are summarized in Table 3. The analysis shows that the instructional approach has a significant effect on students' conceptual understanding, with the experimental group outperforming the control group. In addition, self-efficacy also has a significant effect on learning outcomes, indicating that students' internal beliefs play an important role in academic performance. However, the interaction between instructional approach and self-efficacy was not statistically significant. This suggests that the effectiveness of GeoGebra-supported instruction is consistent across different levels of self-efficacy. From a systems perspective, this indicates that instructional decisions and learner characteristics contribute independently to learning outcomes.

Table 3. Two-Way ANOVA Results

Source	df	F	Sig.
Instructional Approach	1	12.45	0.001
Self-Efficacy	2	9.32	0.000
Instruction × Self-Efficacy	2	1.21	0.304

Taken together, the results indicate that both instructional design and learner-related factors significantly influence students' conceptual understanding. The significant effect of the instructional approach highlights the importance of external instructional decisions, particularly the integration of technology, in shaping learning outcomes. At the same time, the significant effect of self-efficacy demonstrates that internal factors influence how learners engage with learning environments. The absence of an interaction effect suggests that these factors operate independently rather than interactively. From a decision sciences perspective, learning can be understood as a system influenced by both external instructional decisions and internal learner characteristics. Therefore, effective learning environments should consider both dimensions simultaneously to optimize learning outcomes.

Discussion

The findings of this study provide important insights into how instructional decisions and learner characteristics jointly influence conceptual understanding in mathematics learning. The significant improvement observed in students who experienced GeoGebra-supported instruction aligns with previous research highlighting the role of dynamic visualization in enhancing conceptual understanding (Del Cerro & Méndez, 2021; Garzón et al., 2020). By enabling learners to interact with mathematical representations, GeoGebra facilitates the construction of meaningful connections between concepts, which is essential for deep learning (Hiebert & Lefevre, 1986). From a decision sciences perspective, this result underscores the importance of instructional design as a form of strategic decision-making that directly shapes learning environments and outcomes.

In addition, the significant effect of self-efficacy on learning outcomes is consistent with established theories emphasizing the role of belief systems in academic performance (Bandura, 1997; Zimmerman, 2000). Students with higher self-efficacy are more likely to engage in adaptive learning behaviors, such as persistence and strategic problem-solving, which contribute to better conceptual understanding (Schunk & DiBenedetto, 2020). Within the framework of decision sciences, self-efficacy can be viewed as a cognitive factor that influences learners' decision pathways during the learning process. This suggests that improving learning outcomes requires not only effective instructional strategies but also the development of learners' confidence in their own abilities.

However, the absence of a significant interaction effect between instructional approach and self-efficacy presents an interesting finding. This result indicates that the benefits of GeoGebra-supported instruction are relatively stable across different levels of self-efficacy. One possible explanation is that the visual and interactive features of GeoGebra provide sufficient scaffolding to support learners regardless of their initial confidence levels (Mayer, 2009). This finding suggests that well-designed instructional tools can partially compensate for variations in learner characteristics. From a decision-making perspective, this implies that certain instructional decisions may have robust effects that are less dependent on individual differences.

Furthermore, these findings contribute to the broader understanding of learning as a system influenced by multiple interacting factors. While traditional studies often examine instructional methods or psychological variables in isolation, this study highlights the importance of considering both dimensions simultaneously. The results support the view that learning outcomes are shaped by a combination of external instructional decisions and internal learner-related factors (Simon, 1977; Siemens, 2013). However, the lack of interaction suggests that these factors may operate through different pathways rather than through direct interaction. This insight provides a more nuanced understanding of how learning processes unfold in technology-enhanced environments.

Finally, this study extends existing literature by explicitly framing learning within a decision sciences perspective. By integrating instructional design, self-efficacy, and learning outcomes into a single framework, the study offers a more comprehensive approach to understanding learning processes. This perspective emphasizes that both teachers and learners act as decision-makers within the learning environment. Consequently, future research should further explore how decision-making processes can

be modeled and optimized to improve learning outcomes. Overall, the findings contribute to the development of human-centered and data-informed approaches in education, particularly within technology-enhanced learning contexts.

Implication

This study provides both theoretical and practical implications for the development of decision-oriented learning environments. Theoretically, the findings reinforce the view that learning outcomes are shaped by the interplay between instructional decisions and learner-related factors, particularly self-efficacy. By positioning instructional design as a form of decision-making, this study extends existing perspectives in mathematics education and connects them with decision sciences. Practically, the results suggest that integrating dynamic tools such as GeoGebra into instruction can support students' conceptual understanding regardless of their initial confidence levels. This indicates that well-structured instructional decisions can create more inclusive and effective learning environments. Furthermore, educators are encouraged to consider students' psychological characteristics when designing learning activities, as these factors influence how learners engage with instructional interventions. Therefore, this study highlights the importance of combining data-informed instructional design with an understanding of learner behavior to improve educational outcomes.

Limitation and Suggestion for Further Research

Despite its contributions, this study has several limitations that should be considered when interpreting the findings. First, the research was conducted within a specific educational context involving a limited sample from a single school, which may restrict the generalizability of the results. Second, the study focused on a particular instructional approach and technological tool, which may not fully represent the diversity of learning environments and instructional designs. Third, the analysis relied primarily on quantitative data, which may not capture the complexity of students' decision-making processes during learning. In addition, the absence of a direct measurement of decision-making behavior limits the ability to fully explain how instructional and psychological factors interact in shaping learning outcomes. These limitations suggest that further research is needed to explore more diverse contexts and incorporate additional methods. Therefore, the findings should be interpreted as part of an ongoing effort to understand learning as a multidimensional process.

Based on the findings and limitations, several suggestions can be proposed for future research and practice. Future studies are encouraged to incorporate mixed-method approaches to better capture the complexity of decision-making processes in learning environments. Researchers may also explore the use of advanced analytical methods, such as learning analytics or predictive modeling, to strengthen the data-informed perspective in decision sciences. In addition, expanding the scope of research to different educational levels, subjects, and technological tools would enhance the generalizability of findings. From a practical perspective, educators should consider integrating technology not only as a tool but as part of a structured instructional decision framework. Furthermore, interventions aimed at improving students' self-efficacy should be developed alongside instructional innovations to maximize learning outcomes. Therefore, future efforts should

focus on integrating cognitive, technological, and decision-making dimensions in a more comprehensive manner.

CONCLUSION

This study demonstrates that GeoGebra-supported instruction has a significant effect on students' conceptual understanding, while self-efficacy also plays an important role in influencing learning outcomes. Although no interaction effect was found between instructional approach and self-efficacy, both factors contribute independently to students' performance. These findings suggest that learning outcomes are shaped by both external instructional decisions and internal learner characteristics. From a decision sciences perspective, the study highlights the importance of viewing learning as a system influenced by multiple decision-related factors. The results also emphasize that effective instructional design can enhance conceptual understanding even in diverse learner conditions. By integrating technological tools with a decision-oriented framework, this study contributes to the development of more adaptive and human-centered learning environments. Overall, the research provides valuable insights for advancing decision sciences in human learning and development.

AUHOR CONTRIBUTIONS STATEMENT

Suhartini conceptualized the study, designed the research methodology, developed the instructional framework and research instruments, conducted the data collection and statistical analysis, and prepared the initial draft of the manuscript. Indah Marlina Ardianti contributed to the conceptual development of the study, methodological refinement, interpretation of the findings from a science and technology-enhanced learning perspective, and critical review and revision of the manuscript for intellectual and academic content. Both authors contributed to the interpretation and discussion of the findings, reviewed the final manuscript, and approved the final version for publication.

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