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An Exploration of College Students' Algebra Problem-Solving Strategies in a Technology-Based Learning Environment

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ABSTRACT

This qualitative study explores college students' algebra problem-solving strategies in a technology-based learning environment. The study addresses the growing use of digital tools in mathematics learning and the need to understand how students use these tools to construct algebraic reasoning, not merely to obtain answers. A qualitative case study design was used to examine students' experiences, strategies, and reflections in solving algebra problems. The participants consisted of 12 to 15 university students who had experience in technology-based mathematics learning. Data were collected through semi-structured interviews, limited participatory observation, documentation of students' work, screen captures, and researcher reflective notes. Thematic analysis revealed several key themes: students' initial reliance on procedural strategies, the role of digital tools in visualizing algebraic relationships, the shift from trial-and-error to representational reasoning, the tension between technological assistance and conceptual understanding, the role of peer discussion, and students' reflective awareness of errors. The findings show that technology can support algebraic problem solving when students use it to connect symbolic, visual, and contextual representations. However, technology may also create dependence when students use it without conceptual control. This study contributes to mathematics education by highlighting algebra problem solving as a mediated, reflective, and socially situated process. The findings imply that lecturers should design technology-based algebra learning that integrates digital exploration, reasoning prompts, collaborative discussion, and reflective evaluation. Further research may examine different digital tools, broader student groups, and longitudinal changes in students' algebraic reasoning.

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1. Introduction

The development of mathematics learning in higher education has become increasingly shaped by digital technology integration. This shift appears through the use of GeoGebra, learning management systems, instructional videos, interactive quiz applications, visualization tools, and collaborative platforms that help students explore abstract concepts. In the global context, technology no longer functions only as a medium for delivering instructional content. It also creates a learning space where students can build representations, test conjectures, revise strategies, and explain their mathematical thinking processes. Drijvers and Sinclair (2024) explain that digital technology in mathematics education plays an important role in visualization, exploration, communication, and conceptual understanding. Engelbrecht and Borba (2024) also state that recent developments in digital technology have transformed mathematics learning into a more open, interactive, and activity-based process. This condition is highly relevant to algebra learning because algebra requires students to understand symbols, patterns, relations, generalization, and modelling in an integrated way.

In the national context, technology integration in mathematics learning has become stronger after universities expanded online, hybrid, and platform-based learning. Ulya, Sugiman, Rosnawati, and Retnawati (2024) found that technology-based mathematics learning interventions in Indonesia had a positive effect on mathematical problem-solving ability. However, the impact is not always the same in every context. Learning design, student readiness, device availability, and the way lecturers facilitate mathematical interaction also determine the quality of the learning process. Ishartono, Nurcahyo, Waluyo, Prayitno, and Hanifah (2022) showed that GeoGebra integration in flipped learning can support students' self-regulated learning in online mathematics instruction. At the same time, classroom practice still shows that some students use technology instrumentally, such as to obtain quick answers, draw graphs, or check final results, without always understanding the conceptual reasons behind the algebraic procedures they use.

The main problem in algebra learning at the university level lies in the gap between the availability of technology and the quality of students' problem-solving strategies. Algebra does not only require calculation skills. It also requires the ability to transform verbal information into symbolic models, select appropriate representations, explain relationships among variables, and evaluate solutions. Kusuma, Waluya, Rochmad, and Mariani (2024) showed that algebraic thinking ability is closely related to how pre-service teachers understand, analyze, and solve problems using algebraic concepts. Ngu, Yeung, Tobias, and Sweller (2024) explained that solving word problems requires suitable representational strategies, especially when students face complex information. Boaler, Brown, LaMar, Leshin, and Selbach-Allen (2022) added that problem-solving and collaborative learning can influence students' mathematical learning experiences. These findings indicate that algebraic problem-solving strategies need to be understood as cognitive, affective, and social processes, not merely as correct or incorrect answers.

Several empirical studies have proven the benefits of technology in mathematics learning. Chimmalee and Anupan (2022) found that model-eliciting activities supported by cloud technology helped undergraduate students use mathematical concepts to solve problems. Lan, Zhou, Wijaya, Wu, and Purnama (2021) showed that dynamic mathematics software can improve mathematical problem-solving ability. Setiyani, Fitriyani, and Sagita (2020) reported that Quizizz can support problem-solving ability through interactive practice. Meryansumayeka, Zulkardi, Putri, and Hiltrimartin (2022) also showed that ICT-based media can be designed to support higher order thinking skills. However, most of these studies still emphasize effectiveness, score improvement, or learning outcomes. Studies that deeply examine how students interpret technology, choose strategies, move from digital representation to symbolic reasoning, and revise algebraic solutions still need to be expanded through qualitative inquiry.

The need for qualitative research becomes more important because students' experiences in technology-based learning environments cannot always be explained through numerical data. Alabdulaziz (2021) showed that the pandemic accelerated the acceptance of digital technology in mathematics education, but it also raised issues related to readiness, perceived usefulness, and variations in technology use. Borba (2021) explained that the future of mathematics education needs to be understood through the relationship between humans and digital media because technology also shapes ways of thinking and interacting in learning. Bruna, Allahbakhshi, and

Álvarez (2025) found that students' perceptions of digital technology in a linear algebra course are important to examine because students from different academic backgrounds may show different experiences and beliefs. Thurm and Barzel (2020) also emphasized that the use of technology in mathematics learning is influenced by teachers' beliefs, self-efficacy, and prior experiences. Therefore, an exploration of students' strategies in solving algebra problems needs to consider social context, academic culture, learning experience, and students' interaction with digital tools.

Based on this background, this study aims to explore college students' algebra problem-solving strategies in a technology-based learning environment. The study focuses on how students understand problems, choose representations, use digital tools, construct procedures, check solutions, and explain the mathematical reasons behind their steps. This study is important because it can expand understanding of algebraic problem solving as a process that occurs through interaction between symbolic knowledge, visual representation, digital experience, and learning reflection. Theoretically, this study contributes to the development of mathematics education research using a qualitative approach, especially in understanding students' algebraic strategies in digital learning spaces. Practically, the findings can provide a basis for lecturers to design algebra learning that does not only emphasize technology use, but also encourages reasoning, reflection, mathematical communication, and independent learning.

2. Materials and Methods

This study uses a qualitative approach with a case study design. This design was selected because the study focuses on an in-depth exploration of college students' algebra problem-solving strategies within a specific technology-based learning context. A case study allows the researcher to understand students' processes, meanings, experiences, and patterns of action when they solve algebra problems. Susanti, Yulianti, and Noviantari (2025) showed that qualitative analysis of algebra tasks and interviews can help researchers identify students' errors and misconceptions in greater detail. In this study, students' strategies are not examined only through final answers. They are analyzed through how students understand the problem, choose representations, use technology, check their steps, and explain their mathematical reasoning.

The study will be conducted at a university in Indonesia that has implemented technology-based mathematics learning. The learning environment includes the use of a learning management system, GeoGebra, instructional videos, practice applications, and digital discussion platforms. The research is planned to take place from December 2025 to February 2026. The participants are students from a mathematics education program or other study programs who are taking or have completed algebra, linear algebra, or basic mathematics courses involving problem-solving activities. The planned number of participants is 12 to 15 students. This number is selected to obtain data depth, varied experiences, and sufficient information in line with the nature of qualitative research. Wahyuni, Zaiyar, Mazlan, Saragih, and Napitupulu (2023) emphasized that problem-solving ability cannot be fully understood through tests alone. It also needs to be explored through students' responses, observations, and interviews.

Participants will be selected using purposive sampling. The criteria include active student status, prior experience in technology-based mathematics learning, basic ability to use digital devices, willingness to participate in interviews, and experience in solving algebra problems using digital media. The researcher will also consider variations in students' academic ability so that the data can reflect diverse strategies. If the initial data do not show sufficient variation in strategies, snowball sampling may be used by asking lecturers or interviewed students to recommend additional participants. Mufliva, Turmudi, Herman, Iriawan, and Fitriani (2024) showed that selecting participants based on different ability levels and productive struggle can help researchers understand differences in problem-solving processes more clearly.

The data will be collected through semi-structured interviews, limited participatory observation, documentation of students' work, and the researcher's reflective notes. Semi-structured interviews will be used to explore students' experiences in understanding algebra problems, selecting solution steps, using technology, facing difficulties, and checking the correctness of their answers. Observation will be conducted during technology-based problem-solving sessions. The observation will focus on students' behavior when using digital tools, patterns of interaction with peers, responses to lecturer guidance, and the way students move from visual representation to symbolic representation. Documentation will include students' written work, screenshots of application use, solution notes, learning activity records, and supporting documents from the learning platform. Patunah, Caswita, and Suharsono (2024) showed that tests and observation instruments can provide a more complete picture of mathematical problem-solving processes in problem-based learning.

The main instrument in this study is the researcher. Supporting instruments include an interview guide, an observation sheet, algebra problem-solving tasks, and a documentation format. The algebra tasks are designed to encourage students to use more than one strategy, such as symbolic manipulation, graphical representation, tables, patterns, and digital applications. The task focus includes linear equations, systems of equations, functions, algebraic patterns, and contextual problems that require mathematical modelling. Before use, the instruments will be reviewed by two mathematics education experts to ensure content relevance, language clarity, and alignment with the research objectives. The data collection procedure will be conducted in several stages. The researcher will identify potential participants, obtain informed consent, assign algebra problem-solving tasks, conduct observations, carry out interviews, and collect students' work as supporting data.

Data trustworthiness will be maintained through source triangulation, method triangulation, member checking, and an audit trail. Source triangulation will be conducted by comparing data from students, the course lecturer, students' work, and observation notes. Method triangulation will be conducted by comparing interview results, observation findings, documentation, and the researcher's reflective notes. Member checking will be carried out by asking participants to review interview summaries or the researcher's initial interpretations to ensure that the meanings written by the researcher do not deviate from participants' experiences. An audit trail will be maintained by systematically storing research records, including interview transcripts, observation notes, task documents, coding processes, analytical memos, and decisions related to theme development. Ahmed (2024) explained that trustworthiness in qualitative research needs to be built through credibility, transferability, dependability, and confirmability. Through these procedures, the findings are expected to be credible and allow limited replication in similar mathematics learning contexts.

Data analysis will use thematic analysis through systematic stages. The first stage begins with repeated reading of interview transcripts, observation notes, and students' work. The second stage involves initial coding, such as understanding problem information, transforming problems into symbols, using digital applications, trying visual strategies, checking answers, and revising procedures. The third stage groups the codes into broader themes, such as representational strategies, procedural strategies, verification strategies, dependence on technology, conceptual obstacles, and students' reflection on the learning process. Ahmed et al. (2025) explained that thematic analysis can be conducted through data familiarization, coding, searching for themes, reviewing themes, naming themes, and report writing. Kushnir (2025) also emphasized that thematic analysis is relevant in educational research because it helps researchers identify patterns of meaning from learners' experiences. The analysis results will then be presented in a thematic narrative that connects students' strategies, the context of technology use, and their experiences in solving algebra problems.

3. Results and Discussions

The analysis of interview transcripts, classroom observations, students' written work, screen captures, and reflective notes produced four main themes. These themes describe how college students solved algebra problems in a technology-based learning environment. The themes include: students' initial dependence on procedural strategies, the role of digital tools in visualizing algebraic relationships, the shift from trial-and-error to representational reasoning, and the tension between technological assistance and conceptual understanding. These themes show that students' algebra problem-solving strategies did not develop in a linear way. Instead, students moved between symbolic manipulation, visual interpretation, peer discussion, digital checking, and reflective correction.

The first theme shows that many students began solving algebra problems through procedural strategies. Most participants first tried to identify formulas, isolate variables, substitute values, or follow steps that they had memorized from previous lessons. This pattern appeared clearly in tasks involving linear equations, systems of equations, and algebraic functions. Several students stated that they felt more secure when they could connect a problem with a familiar procedure. One participant explained, "I usually look for the formula first because it helps me know where to start" (P3). Another student stated, "When the problem looks different from the example, I get confused, even if the concept is actually the same" (P7). These responses indicate that procedural knowledge still shaped students' first response to algebra problems. However, observation data showed that students often stopped when their memorized procedures did not fit the problem structure.

The second theme concerns the role of digital tools in helping students visualize algebraic relationships. GeoGebra, graphing applications, and digital worksheets helped students see connections between equations, graphs, and numerical patterns. Students who initially struggled with symbolic forms could explain the meaning of a function more clearly after viewing its graph. One student said, "When I saw the graph, I understood why the line changed when the coefficient changed" (P5). Another participant stated, "The application helped me check whether my equation made sense" (P11). This finding suggests that technology supported students in connecting symbolic and visual representations. During observation, students frequently used digital graphs to test their assumptions before finalizing their written solutions. This strategy helped them detect errors in signs, coefficients, and variable relationships.

The third theme shows a gradual shift from trial-and-error strategies to representational reasoning. At the beginning of the task, several students entered values into digital tools without a clear plan. They used technology to test possible answers, adjust equations, and compare outputs. However, after discussion and reflection, some students began to explain why certain representations were more useful than others. For example, one participant explained, "At first I only tried numbers, but after seeing the table and graph, I knew the pattern was linear" (P2). Another student said, "The graph did not give the answer directly, but it helped me understand what the equation represented" (P9). These statements show that technology became more meaningful when students used it to support reasoning, not only to produce answers. The documentation of student work also showed improvement in how students linked tables, graphs, and equations.

The fourth theme reveals a tension between technological assistance and conceptual understanding. Some students relied heavily on digital tools to validate answers but could not always explain the mathematical reasoning behind the results. This pattern appeared when students used applications to solve equations automatically. One participant admitted, "I can get the answer from the application, but sometimes I do not know why the steps are like that" (P6). Another student said, "Technology makes it faster, but I still need the lecturer to explain the meaning" (P10). This finding indicates that technology can support learning, but it can also create superficial problem-solving if students treat it as a shortcut. Observations showed that students with stronger conceptual understanding used technology as a checking and exploration tool, while students with weaker understanding tended to use it as a substitute for reasoning.

The fifth finding relates to social interaction in technology-based learning. Students often developed stronger explanations after discussing their digital results with peers. Peer discussion helped them compare strategies, correct errors, and verbalize their reasoning. One student noted, "When my friend used another method, I realized that my graph and equation should match" (P4). Another participant stated, "I understood the problem better after explaining my answer to my group" (P12). These data show that algebra problem solving in a technology-based environment was not only an individual cognitive process. It also involved communication, negotiation of meaning, and shared interpretation. The classroom environment influenced how students used technology. When the lecturer encouraged explanation and comparison of strategies, students showed deeper engagement with algebraic reasoning.

The final theme concerns students' reflection on their own learning strategies. Several participants reported that technology helped them become more aware of their errors. They could compare their written solution with the output from a digital tool, then revise their work. One student explained, "I found my mistake because the graph did not match my equation" (P8). Another said, "After using the application, I checked again which step was wrong" (P1). These reflections show that technology can support metacognitive activity when students use it to monitor and evaluate their thinking. However, this process required guidance. Students who received prompts to explain, compare, and justify their answers produced richer reflections than students who only used digital tools for calculation.

Discussion

The findings show that students' algebra problem-solving strategies in a technology-based learning environment are shaped by the interaction between procedural knowledge, visual representation, digital exploration, and social discussion. This result supports the view that digital technology in mathematics education functions not only as a technical tool, but also as a medium that shapes mathematical activity. Drijvers and Sinclair (2024) argue that technology supports visualization, exploration, and communication in mathematics learning. The present study extends this view by showing that students benefit most from technology when they use it to connect representations and justify reasoning. Technology becomes meaningful when it helps students move from "getting an answer" to "understanding a relationship."

The finding that students initially relied on procedural strategies is consistent with previous studies on algebra learning. Students often begin with familiar formulas or memorized steps because these procedures provide a sense of security. Kusuma, Waluya, Rochmad, and Mariani (2024) found that algebraic thinking is related to students' ability to understand and analyze mathematical problems, not only to carry out procedures. The present study confirms this point. Students who only depended on formulas struggled when the problem structure changed. In contrast, students who could connect symbols, graphs, and contextual meanings showed more flexible strategies. This suggests that algebra instruction should not separate procedural fluency from conceptual reasoning.

The role of visualization also became a central finding. Digital tools helped students interpret equations, functions, and systems of equations through graphs, tables, and dynamic changes. This finding aligns with Lan, Zhou, Wijaya, Wu, and Purnama (2021), who reported that dynamic mathematics software can improve mathematical problem-solving ability. It also supports the work of Chimmalee and Anupan (2022), who showed that technology-supported activities can help undergraduate students apply mathematical concepts in problem-solving situations. However, the present study adds a qualitative explanation of how this process occurred. Students used visual outputs to check assumptions, identify errors, and understand relationships among variables.

At the same time, the study found that technology can create dependence when students use it without conceptual control. Some participants could obtain correct answers from applications but could not explain the reasoning behind the steps. This finding is important because it shows that access to technology does not automatically produce deeper understanding. Alabdulaziz (2021) noted that digital technology use in mathematics education depends on readiness, perception, and patterns of implementation. The present study supports this argument by showing that students' use of technology varied. Some students used it for exploration and verification, while others used it mainly for answer generation. This difference indicates the need for instructional design that requires students to explain, compare, and justify digital results.

The shift from trial-and-error to representational reasoning offers an important theoretical contribution. Students did not immediately use technology in a reflective way. Many began by testing numbers or checking answers. Over time, with prompts and discussion, they began to connect tables, graphs, equations, and contextual meanings. This finding is consistent with Borba's (2021) argument that mathematical thinking develops through interaction between humans and media. In this study, digital tools shaped the way students noticed patterns, revised errors, and explained algebraic relationships. However, this interaction became productive only when students engaged in reflection. Therefore, technology-based learning should include structured tasks that guide students to interpret what the tool shows.

The role of peer discussion also strengthens the understanding of algebra problem solving as a social process. Students developed clearer reasoning when they compared strategies with classmates. This finding is in line with Boaler, Brown, LaMar, Leshin, and Selbach-Allen (2022), who showed that problem-solving and collaboration can influence students' mathematics learning experiences. In the present study, collaboration helped students recognize mismatches between equations and graphs, explain procedures, and revise solutions. This indicates that technology-based algebra learning should not be designed only as individual screen-based activity. It should also create opportunities for dialogue, argumentation, and shared reasoning.

The findings also support the need for qualitative inquiry in mathematics education. Quantitative studies can show whether technology improves scores, but they cannot fully explain how students use technology, why they choose certain strategies, and how they interpret their own errors. Bruna, Allahbakhshi, and Álvarez (2025) showed that students' perceptions of digital technology in linear algebra are important because learners may experience the same tool differently. The present study contributes to this discussion by showing that students' strategies are influenced by prior knowledge, confidence, peer interaction, task design, and lecturer guidance. These factors shape whether technology supports conceptual understanding or only accelerates procedural work.

Practically, the findings suggest that lecturers need to design algebra learning activities that combine digital tools with reasoning-based prompts. Students should not only be asked to solve problems using technology. They should also be asked to explain why a graph represents an equation, compare symbolic and visual solutions, identify errors, and reflect on the strategy they used. Setiyani, Fitriyani, and Sagita (2020) showed that digital platforms such as Quizizz can support problem-solving practice, while Meryansumayeka, Zulkardi, Putri, and Hiltrimartin (2022) emphasized the role of ICT media in supporting higher order thinking skills. The present study suggests that this potential can be strengthened when technology use is connected with explanation, reflection, and mathematical communication.

Theoretically, this study contributes to the understanding of algebra problem solving as a dynamic process that involves symbolic reasoning, visual representation, technological mediation, and social interaction. The findings show that students' strategies cannot be reduced to correct procedures. They include how students interpret a problem, select a representation, use a tool, negotiate meaning, and revise their thinking. This perspective enriches technology-based mathematics education by showing that digital tools function as part of the learning ecology. They influence what students see, how they test ideas, and how they communicate mathematical meaning.

Further research can explore this topic in broader contexts. Future studies may compare students from different study programs, examine specific digital tools such as GeoGebra or Desmos in greater depth, or analyze how lecturers' scaffolding influences students' algebraic reasoning. Longitudinal research may also examine how students' strategies change across one semester of technology-based algebra learning. In addition, future studies can combine qualitative data with learning analytics from digital platforms to understand both the process and pattern of students' problem-solving behavior. Such research can deepen understanding of how technology supports meaningful algebra learning in higher education.

4. Conclusions

This study concludes that college students' algebra problem-solving strategies in a technology-based learning environment are shaped by the interaction between procedural knowledge, visual representation, digital exploration, peer discussion, and reflective evaluation. The findings show that students often begin with memorized procedures, but digital tools help them connect equations, graphs, tables, and contextual meanings when the learning process includes explanation and reflection. Technology supports algebraic understanding most effectively when students use it to test assumptions, identify errors, compare representations, and justify their reasoning. However, the study also shows that technology can lead to superficial problem solving when students use it mainly to obtain quick answers without understanding the underlying concepts.

Theoretically, this study contributes to qualitative mathematics education research by showing that algebra problem solving is not only a cognitive process, but also a mediated and social process shaped by digital tools, classroom interaction, and students' learning experiences. Practically, the findings suggest that lecturers should design technology-based algebra learning that combines digital exploration with reasoning-based prompts, peer discussion, and reflective tasks. From a policy perspective, universities need to support digital mathematics learning through lecturer training, adequate learning platforms, and instructional guidelines that emphasize conceptual understanding rather than tool use alone. Future studies may examine larger and more varied participant groups, compare different digital tools, or use longitudinal designs to understand how students' algebraic reasoning develops over time.

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