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Digital Visualization Tools and Mathematical Proficiency: A Correlational Study of Desmos, GeoGebra, Conceptual Understanding, and Student Engagement in Calculus

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Abstract

This study examined the relationship between the utilization of digital visualization tools, specifically Desmos and GeoGebra, and the mathematical proficiency of Grade 11 STEM students in Calculus, focusing on conceptual understanding and behavioral, emotional, and cognitive engagement. Anchored in Constructivist Learning Theory and Dual Coding Theory, the study employed a descriptive-correlational design involving 134 Grade 11 STEM students at Liceo de San Pedro selected through purposive sampling. Data were collected using a validated researcher-made structured questionnaire and analyzed using mean, standard deviation, and Pearson Product-Moment Correlation. The findings showed high utilization of interactive graphing, dynamic manipulation of functions, visual representation of concepts, and real-time feedback, alongside high levels of conceptual understanding and student engagement. Digital visualization utilization had significant positive relationships with behavioral, emotional, and cognitive engagement ($r = .577–.720$, $p = .001$) and conceptual understanding ($r = .621–.698$, $p < .001$). Dynamic manipulation of functions showed the strongest relationships with cognitive engagement and conceptual understanding. The study concluded that digital visualization tools are significantly associated with mathematical proficiency but, due to the correlational design, do not establish causality. It recommends consistent integration of Desmos and GeoGebra, teacher preparation, visualization-based curricular activities, and further experimental research. The study aligns with SDG 4 – Quality Education by supporting meaningful, student-centered, technology-enhanced mathematics learning. Its sustainability impact centers on educational and technological sustainability through the purposeful integration of digital visualization to support sustained improvements in Calculus teaching, conceptual learning, and student engagement.

Keywords: Calculus, Conceptual Understanding, Desmos, Digital Visualization Tools, Geogebra, Mathematical Proficiency, Student Engagement, Technology-Supported Instruction

1. Introduction

The integration of digital technologies into mathematics education has expanded opportunities for teaching abstract concepts through interactive and visual representations. In Calculus, digital visualization tools such as Desmos (Desmos Studio PBC, 2024) and GeoGebra (GeoGebra Team, 2024) provide interactive environments in which students can manipulate functions, observe graphical changes, and connect symbolic expressions with visual representations. Research indicates that these visualization-supported activities can contribute to deeper conceptual understanding (Alvarez & Galman, 2024; Schoenherr et al., 2024; Zhang et al., 2025). More broadly, a meta-analysis by Hillmayr et al. (2020) demonstrated the potential of digital tools to enhance mathematics and science learning in secondary schools, while emphasizing that their effectiveness depends on the instructional context in which they are used. Visualization-based instruction can further strengthen mathematical reasoning by making relationships among variables and functions more concrete (Chytas et al., 2024). Beyond conceptual understanding, digital visualization may influence student engagement, including behavioral participation, emotional involvement, and cognitive processing. Interactive digital environments can encourage active participation, enjoyment, and deeper engagement with mathematical tasks (Tesfamicael, 2022). However, limited research has examined how specific dimensions of digital visualization utilization relate simultaneously to conceptual understanding and multiple dimensions of student engagement, particularly among Philippine senior high school students. This study therefore examines the relationships among Desmos and GeoGebra utilization, conceptual understanding, and behavioral, emotional, and cognitive engagement among Grade 11 STEM students learning Calculus.

Calculus requires students to understand abstract concepts such as limits, derivatives, and integrals while developing both procedural fluency and conceptual comprehension. Digital visualization tools provide dynamic graphs, simulations, sliders, and real-time manipulation of variables that enable learners to observe mathematical relationships rather than rely exclusively on symbolic representations. The educational role of graphing is also reflected in systematic research examining empirical studies on graphing numerical data across K–12 STEM education (Ruf et al., 2026). By connecting graphical and symbolic forms, Desmos and GeoGebra can make abstract mathematical ideas more accessible and support conceptual reasoning (Alvarez & Galman, 2024; Zhang et al., 2025). Visualization-based instruction likewise strengthens students' interpretation of mathematical relationships and conceptual reasoning (Chytas et al., 2024). Mathematical proficiency in this study is considered through conceptual understanding and student engagement. Conceptual understanding involves interpreting graphs, connecting symbolic and visual representations, and explaining mathematical ideas, while engagement encompasses behavioral, emotional, and cognitive participation in learning. Digital visualization is relevant to both outcomes because its interactive features provide opportunities for students to explore mathematical ideas actively while receiving immediate visual representations of their actions.

Existing research demonstrates the educational value of digital visualization in mathematics. A systematic literature review by Izdahara and Irvan (2024) examined the effectiveness of GeoGebra in mathematics education in the digital era, providing broader support for its use as a technology-assisted mathematics learning tool. Previous studies have examined its effects on academic achievement, conceptual understanding, engagement, and mathematical thinking, showing that Desmos and GeoGebra can support mathematics learning (Alvarez & Galman, 2024; Chytas et al., 2024; Oktafia & Erita, 2025; Tesfamicael, 2022). Digital visualization supports conceptual learning by allowing students to manipulate graphs, examine function behavior, and connect multiple representations. Alvarez and Galman (2024) found that students using Desmos to learn function behavior improved their graphical interpretation and conceptual understanding. Similarly, Canonigo (2024) reported improvements in students' conceptual understanding when technology-supported tools, including GeoGebra, were incorporated into mathematics instruction. Azra (2025) further reported that visualization tools help make non-linear functions more concrete and interactive. Chytas et al. (2024) emphasized the contribution of dynamic graphing environments to students' ability to connect multiple mathematical representations. Within the Philippine context, De Las Peñas et al. (2024) demonstrated the potential of GeoGebra applets designed for algebra to foster conceptual understanding through interactive mathematical representations. Evidence from secondary mathematics contexts further supports the role of GeoGebra in conceptual learning. Gurmu et al. (2024) found that GeoGebra-supported collaborative instruction produced stronger conceptual understanding of geometry among Grade 10 students than the comparison instructional approaches. Hidayat et al. (2024) likewise reported favorable outcomes related to conceptual understanding and student engagement when GeoGebra was used in teaching functions and quadratic equations. Visualization is also associated with student engagement. Digital visualization environments can promote participation, enjoyment, and deeper cognitive processing (Pope, 2023; Tesfamicael, 2022). The integration of GeoGebra in secondary mathematics classrooms has also been examined in relation to changes in students' mathematical attitudes (Romero Albaladejo & García López, 2024). More broadly, research has examined the relationship between technology use and student engagement in STEM learning environments (Scherer et al., 2021). Chiu (2021) further demonstrated that appropriately designed digital support can enhance student engagement in technology-supported learning environments by addressing learners' needs for autonomy, competence, and relatedness.

The broader literature establishes the potential of digital visualization for mathematics education, but evidence remains limited regarding the relationships among its specific dimensions and mathematical proficiency within the Philippine senior high school context. Existing research has largely concentrated on experimental interventions and separate learning outcomes rather than relational analysis involving conceptual understanding and behavioral, emotional, and cognitive engagement. Addressing this context is particularly relevant to Grade 11 STEM students studying Calculus, where learners encounter concepts requiring interpretation across symbolic and graphical representations. The present study consequently focuses on the utilization of Desmos and GeoGebra through interactive graphing, dynamic manipulation of functions, visual representation of concepts, and real-time feedback. These dimensions are examined in relation to conceptual understanding and the behavioral, emotional, and cognitive dimensions of student engagement.

The study is anchored in the Constructivist Learning Theory by Jean Piaget (1970), which explains learning as an active process of constructing knowledge through experience and interaction. Applied to Calculus, this perspective suggests that students develop understanding more effectively when they explore and manipulate mathematical concepts instead of receiving information passively. Desmos and GeoGebra support this process by enabling students to manipulate graphs, observe changes, and independently identify relationships among mathematical representations. Evidence supporting this theoretical perspective indicates that visualization can strengthen conceptual understanding and problem-solving. Alvarez and Galman (2024) associated Desmos use with improved graphical interpretation and conceptual understanding, while Azra (2025) emphasized the role of digital visualization in making abstract non-linear functions concrete and interactive. Chytas et al. (2024) further highlighted the value of dynamic graphing environments in connecting multiple representations of mathematical concepts. The study is also supported by the Dual Coding Theory by Allan Paivio (1986), which proposes that learning becomes more effective when information is represented through both verbal and visual forms. In Calculus, combining symbolic equations with graphical representations may improve comprehension and retention of abstract concepts. Tesfamicael (2022) reinforced this perspective by showing that visual-based environments such as GeoGebra can support cognitive engagement and retention through the integration of symbolic and visual processing during mathematical problem-solving. Together, these theories explain the study's conceptual relationship: digital visualization through Desmos and GeoGebra facilitates active exploration and combines visual and symbolic representations, which are associated with conceptual understanding and behavioral, emotional, and cognitive engagement. Thus, digital visualization tool utilization serves as the principal variable examined in relation to the mathematical proficiency outcomes of conceptual understanding and student engagement.

Although previous studies demonstrate the educational benefits of digital visualization, limited research has examined the correlational relationships between specific dimensions of digital visualization utilization and both conceptual understanding and student engagement among Philippine senior high school students. Most previous investigations have emphasized experimental effects or considered academic achievement, conceptual understanding, and engagement as separate outcomes (Alvarez & Galman, 2024; Chytas et al., 2024; Tesfamicael, 2022). The present study addresses this gap by investigating how interactive graphing, dynamic manipulation of functions, visual representation of concepts, and real-time feedback are related to Grade 11 STEM students' conceptual understanding and behavioral, emotional, and cognitive engagement in Calculus. This relational approach provides a basis for determining whether higher utilization of digital visualization tools is associated with stronger mathematical proficiency without assuming causal relationships. Accordingly, the study seeks to determine the level of utilization of Desmos and GeoGebra, assess students' conceptual understanding and engagement, establish whether significant relationships exist between these variables, and provide a basis for an action plan or intervention program to enhance the integration of digital visualization tools in Calculus instruction.

The study is most directly aligned with SDG 4 – Quality Education because it examines an instructional approach intended to support meaningful and student-centered mathematics learning. Desmos and GeoGebra provide interactive environments through which students can explore abstract Calculus concepts, connect symbolic and graphical representations, and participate more actively in learning. The study's focus on conceptual understanding and behavioral, emotional, and cognitive engagement therefore relates to improving the quality of students' learning experiences through appropriate educational technology. This alignment is reinforced by the study's emphasis on determining how digital visualization can be integrated more effectively into Calculus instruction. Rather than treating technology as an end in itself, the research examines its relationship with specific learning outcomes and provides a basis for strengthening visualization-supported mathematics instruction among Grade 11 STEM students.

The study contributes primarily to educational and technological sustainability by examining how digital visualization tools can support sustained improvements in the teaching and learning of abstract mathematics.

Educationally, the integration of interactive graphing, dynamic manipulation, visual representation, and real-time feedback provides learners with alternative ways of constructing and interpreting mathematical knowledge. These processes support the development of conceptual understanding while encouraging behavioral, emotional, and cognitive involvement in learning. From a technological sustainability perspective, the study considers digital tools as instructional supports whose value depends on their meaningful integration into teaching and learning. The theoretical framework further emphasizes that technology becomes educationally relevant when it facilitates active knowledge construction and connects visual and symbolic information. Through the combined perspectives of Constructivist Learning Theory by Jean Piaget (1970) and Dual Coding Theory by Allan Paivio (1986), the study situates Desmos and GeoGebra within a learner-centered approach to mathematics education rather than viewing digital technology merely as an additional classroom resource. By investigating the relationships among digital visualization utilization, conceptual understanding, and student engagement among Grade 11 STEM students, the research provides evidence relevant to the continuing improvement of technology-supported Calculus instruction. Its multidisciplinary significance lies in connecting mathematics education, educational technology, cognitive learning processes, and student engagement toward more meaningful and sustainable learning experiences.

2. Material and methods

2.1 Research Design

The study employed a descriptive-correlational research design to determine the relationship between the utilization of digital visualization tools and students' conceptual understanding and engagement in Calculus. This design enabled the researchers to describe the levels of digital visualization tool utilization, conceptual understanding, and student engagement and to examine the statistical relationships among these variables.

2.2 Locale of the Study

The study was conducted at Liceo de San Pedro, where the participating Grade 11 STEM students were enrolled in Calculus. The manuscript provides no additional description of the study locale.

2.3 Respondents of the Study

The respondents consisted of 134 Grade 11 STEM students enrolled in Calculus at Liceo de San Pedro. Eligible participants had prior or current experience using Desmos and/or GeoGebra in learning Calculus, ensuring that the respondents had relevant exposure to the digital visualization tools examined in the study.

2.4 Sample and Sampling Procedure

The study used purposive sampling to select Grade 11 STEM students with prior or current experience using Desmos and/or GeoGebra in Calculus. The required sample size was determined using G*Power version 3.1.9.4 based on a medium effect size ($r = 0.30$), an alpha level of 0.05, and a statistical power of 0.80. The resulting sample of 134 respondents was considered adequate for detecting significant relationships through correlational analysis.

2.5 Research Instrument

Data were collected using a validated researcher-made structured questionnaire covering three areas: utilization of digital visualization tools, student engagement, and conceptual understanding in Calculus. Student engagement encompassed behavioral, emotional, and cognitive dimensions. The instrument underwent content validation by two experts in Mathematics Education and Research Methodology, who evaluated its content validity, clarity of instructions, appropriateness of indicators, and alignment with the research objectives. Their comments and recommendations were incorporated before the questionnaire was administered. The instrument was pilot-tested among 30 Grade 11 STEM students from Liceo de San Pedro who were excluded from the final sample. Cronbach's alpha was used to establish reliability, producing coefficients of $\alpha = 0.71$ for Digital Visualization Tools, $\alpha = 0.70$ for Student Engagement, and $\alpha = 0.72$ for Conceptual Understanding. These values indicated acceptable internal consistency and supported the instrument's suitability for measuring the study variables.

2.6 Data Gathering Procedure

Permission to conduct the research was obtained from the administration of Liceo de San Pedro through the School Principal on June 17, 2026 prior to data collection. After the necessary permission and consent requirements were satisfied, the questionnaire was administered through printed copies and/or an online platform depending on respondents' accessibility and availability. The collected responses were subsequently prepared for descriptive and inferential statistical analysis.

2.7 Data Analysis Techniques

The collected data were analyzed using descriptive and inferential statistics. Mean and standard deviation were used to determine the levels of digital visualization tool utilization, student engagement, and conceptual understanding. Pearson Product-Moment Correlation was employed to examine significant relationships between digital visualization tool utilization and students' conceptual understanding and engagement. Before correlation analysis, the assumptions of normality, linearity, homoscedasticity, and interval-level measurement were assessed and found satisfactory. The statistical results provided the basis for drawing conclusions and developing the proposed action plan for enhancing students' learning experiences in Calculus.

2.8 Ethical Considerations

Ethical considerations were observed throughout the research process. Participation was voluntary, and informed consent was obtained from all respondents. For participants who were minors, parental consent and student assent were secured before participation. The confidentiality and anonymity of respondents were maintained, and all collected information was used solely for academic and research purposes.

3. Results and Discussion

3.1 Utilization of Digital Visualization Tools in Calculus

3.1.1 Interactive Graphing

Interactive graphing obtained a general mean of 3.67 and a standard deviation of 0.548, indicating strong agreement and consistent student perceptions. The ability to see how graphs change when variables are adjusted received the highest mean of 3.80, while independent exploration of graphs received the lowest mean of 3.55, although it remained within the Strongly Agree category. These results indicate that interactive graphing through Desmos and GeoGebra supports students' understanding of Calculus functions by enabling them to observe relationships between variables dynamically. The immediate graphical representation of mathematical changes makes abstract concepts more concrete and accessible.

3.1.2 Dynamic Manipulation of Functions

Dynamic manipulation of functions obtained a general mean of 3.67 and a standard deviation of 0.531. Students reported the strongest agreement for their ability to manipulate functions through stretching, shifting, and compressing, with a mean of 3.78. The lowest mean was 3.58 for exploring function behavior without relying solely on memorized formulas, which was still interpreted as Strongly Agree. The findings indicate that dynamic manipulation through Desmos and GeoGebra strengthens students' understanding of function transformations. By allowing mathematical changes to be observed in real time, these tools provide opportunities to explore relationships dynamically rather than depend exclusively on symbolic representations.

3.1.3 Visual Representation of Calculus Concepts

Visual representation of concepts obtained a general mean of 3.66 and a standard deviation of 0.556. Students rated the usefulness of visual models for understanding abstract Calculus concepts highest at 3.75, while improved retention of Calculus lessons received the lowest mean of 3.55. All indicators remained within the Strongly Agree category. The findings demonstrate the importance of visualization in connecting abstract and concrete mathematical understanding. Visual representations allow students to relate graphical and symbolic forms and facilitate comprehension of topics such as limits, functions, and continuity.

3.1.4 Real-Time Feedback

Real-time feedback recorded the highest overall utilization among the digital visualization dimensions, with a general mean of 3.68 and a standard deviation of 0.512. Immediately seeing the results of inputs in Desmos/GeoGebra received the highest mean of 3.82, while the contribution of real-time feedback to engagement in problem solving received the lowest mean of 3.58. Responses nevertheless indicated strong agreement across all indicators. The findings indicate that immediate visual feedback supports learning efficiency by enabling students to evaluate their mathematical inputs and identify or correct errors quickly. This feature allows learners to observe the consequences of mathematical actions directly and refine their understanding while solving Calculus problems.

3.2 Mathematical Proficiency of Grade 11 STEM Students

3.2.1 Conceptual Understanding in Calculus

Conceptual understanding obtained a general mean of 3.71 and a standard deviation of 0.527, indicating a high and consistent level among the students. The ability to explain Calculus concepts using graphs and visual representations obtained the highest mean of 3.78, while applying Calculus concepts to problem-solving situations obtained the lowest mean of 3.65. Both results remained within the Strongly Agree category. The findings suggest that digital visualization supports the construction of mathematical meaning by helping students connect abstract Calculus concepts with graphical representations. The comparatively lower rating for applying concepts to problem-solving situations indicates that students may require additional opportunities to transfer their conceptual knowledge to more complex problem contexts.

3.2.2 Behavioral Engagement

Behavioral engagement obtained a general mean of 3.71 and a standard deviation of 0.533, indicating high and consistent participation when digital visualization tools were used. Spending more time exploring problems with visualization tools received the highest mean of 3.80, while attentiveness during lessons involving digital visualization received the lowest mean of 3.65. The results indicate that the interactive and visual features of Desmos and GeoGebra encourage active participation, sustained effort, and involvement in classroom activities. Graphical representations appear to encourage students to explore solutions, revisit concepts, and engage in extended mathematical thinking, although attentiveness may vary according to the activity and complexity of the lesson.

3.2.3 Emotional Engagement

Emotional engagement obtained the highest general mean among the engagement dimensions at 3.72, with a standard deviation of 0.512. Enjoyment in learning Calculus using Desmos and GeoGebra received the highest mean of 3.85, while perceiving visualization as making Calculus more interesting obtained the lowest mean of 3.60. All indicators were interpreted as Strongly Agree. These findings indicate that digital visualization positively influences students' emotional experiences by increasing enjoyment, confidence, and motivation while reducing anxiety when learning complex mathematical concepts. However, the relatively lower rating for interest suggests that some Calculus topics may remain challenging despite visualization. Overall, the interactive features of Desmos and GeoGebra contribute to a more positive learning environment.

3.2.4 Cognitive Engagement

Cognitive engagement obtained a general mean of 3.71 and a standard deviation of 0.518. Students most strongly agreed that they understand Calculus concepts better when visualized, with a mean of 3.83, while deeper analysis of functions using Desmos and GeoGebra received the lowest mean of 3.60. The findings indicate that visualization strengthens students' ability to understand, analyze, and connect mathematical concepts. Presenting abstract ideas graphically facilitates meaning construction and connects formulas with visual representations. The comparatively lower rating for deeper function analysis suggests that more guided instruction or complex activities may be necessary to develop higher levels of cognitive engagement.

3.3 Relationship Between Digital Visualization and Student Engagement

3.3.1 Behavioral, Emotional, and Cognitive Engagement

Digital visualization utilization demonstrated significant positive relationships with all three dimensions of student engagement, with correlation coefficients ranging from .577 to .720 and $p = .001$. Interactive graphing was associated with behavioral ($r = .612$), emotional ($r = .645$), and cognitive engagement ($r = .701$). Dynamic manipulation of functions was associated with behavioral ($r = .589$), emotional ($r = .633$), and cognitive engagement ($r = .720$). Visual representation of concepts was associated with behavioral ($r = .601$), emotional ($r = .668$), and cognitive engagement ($r = .712$), while real-time feedback was associated with behavioral ($r = .577$), emotional ($r = .640$), and cognitive engagement ($r = .695$). The strongest relationship was between dynamic manipulation of functions and cognitive engagement ($r = .720$). The findings are consistent with Azra (2025) and Zhang et al. (2025), who reported that digital visualization tools improve students' understanding by allowing interaction with dynamic representations of mathematical functions and relationships. Likewise, Tesfamicael (2022) found higher cognitive engagement among students using GeoGebra and Desmos because these tools promote exploration, reflection, and self-regulated learning. The results also align with Alvarez and Galman (2024), who reported that Desmos supports connections between graphical and symbolic mathematical representations. Behavioral engagement showed relatively weaker relationships with digital visualization than cognitive engagement. This suggests that although visualization directly supports reasoning, analysis, and conceptual processing, observable participation may also depend on instructional design, classroom management, and individual motivation. Consequently, digital visualization alone may not ensure active participation without well-structured learning activities.

3.4 Relationship Between Digital Visualization and Conceptual Understanding

3.4.1 Digital Visualization Dimensions and Conceptual Understanding

All dimensions of digital visualization showed statistically significant positive relationships with conceptual understanding at $p < .001$. Dynamic Manipulation of Functions had the strongest relationship ($r = .698$, $p < .001$), followed by Visual Representation of Concepts ($r = .682$, $p < .001$), Interactive Graphing ($r = .654$, $p < .001$), and Real-Time Feedback ($r = .621$, $p < .001$). These coefficients indicate moderate-to-strong positive relationships, leading to the rejection of the null hypothesis of no significant relationship between digital visualization and conceptual understanding. The findings indicate that students with higher levels of engagement with digital visualization features also tend to demonstrate higher conceptual understanding in Calculus. Dynamic manipulation appears particularly relevant because opportunities to manipulate mathematical representations allow students to explore abstract concepts interactively. Interactive graphing, visual representation, and real-time feedback similarly provide visual and interactive learning experiences associated with students' conceptual development.

3.4.2 Theoretical Interpretation of the Relationships

The significant relationships support Piaget's Constructivist Learning Theory because students interact directly with mathematical representations by manipulating graphs, observing patterns, and exploring relationships among variables. Such activities allow learners to construct mathematical knowledge through active exploration rather than passive reception. The results also reinforce Paivio's Dual Coding Theory, which proposes that learning is enhanced when information is processed through verbal-symbolic and visual channels. Students' high conceptual understanding and cognitive engagement indicate benefits from simultaneously working with equations, graphs, and dynamic visual models, thereby supporting comprehension and retention of Calculus concepts.

3.5 Implications and Limits of the Findings

The overall findings demonstrate that digital visualization tools are significantly associated with conceptual understanding and student engagement in Calculus. The results support the regular integration of Desmos and GeoGebra into instruction, teacher preparation for visualization-based and inquiry-oriented lessons, incorporation of visualization activities into mathematics curricula, and adequate access to technological resources. Digital visualization therefore functions as an instructional support for conceptual learning, cognitive engagement, and meaningful Calculus learning experiences. However, the findings establish associations rather than causal relationships. Higher utilization of Desmos and GeoGebra was associated with higher engagement and conceptual understanding, but the descriptive-correlational design does not demonstrate that digital visualization directly caused these outcomes. Students' prior mathematical knowledge, motivation, teaching strategies, classroom environment, and access to technological resources may also have contributed to the observed relationships. Future studies employing experimental or longitudinal research designs are recommended to further examine the causal effects of digital visualization tools on students' mathematical learning.

4. Conclusion & Recommendations

The study concludes that the utilization of digital visualization tools such as Desmos and GeoGebra is significantly associated with Grade 11 STEM students' conceptual understanding and behavioral, emotional, and cognitive engagement in Calculus. The findings indicate that interactive graphing, dynamic manipulation of functions, visual representation of concepts, and real-time feedback support students in connecting symbolic and graphical representations, understanding abstract mathematical concepts, and engaging more meaningfully in learning activities. Dynamic manipulation of functions showed particularly strong relationships with conceptual understanding and cognitive engagement, emphasizing the value of active exploration and interactive visualization. Overall, digital visualization tools function as cognitive and instructional supports for mathematical proficiency, although their effectiveness depends on intentional integration into teaching strategies.

Mathematics teachers are recommended to consistently integrate Desmos and GeoGebra into Calculus instruction to strengthen students' conceptual understanding and engagement through interactive visualization. Schools should provide structured teacher training on effective digital visualization strategies, while curriculum planners should incorporate visualization-based activities into the Mathematics curriculum to promote conceptual learning and student-centered instruction. Future researchers should employ experimental research designs to further investigate causal relationships between digital visualization tool utilization and students' mathematical proficiency outcomes.

The study is limited by its descriptive-correlational design, which establishes significant associations between digital visualization tool utilization, student engagement, and conceptual understanding but does not establish causality. Although greater utilization of Desmos and GeoGebra was associated with higher levels of engagement and conceptual understanding, the findings cannot demonstrate that these tools directly caused improvements in students' learning outcomes. Other factors, including prior mathematical knowledge, learning motivation, teaching strategies, classroom environment, and access to technological resources, may have contributed to the observed relationships.

5. Compliance with ethical standards

The authors observed ethical considerations throughout the research process. They obtained permission to conduct the study from the administration of Liceo de San Pedro through the School Principal prior to data collection. The authors ensured that participation was voluntary and that informed consent was obtained from all respondents. For participants who were minors, parental consent and student assent were secured before participation. They also maintained the confidentiality and anonymity of the respondents and ensured that all information collected was used solely for academic and research purposes.

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