

EXPLORING STUDENT PERCEPTIONS: VISUALIZING ABSTRACT CONCEPTS IN DESCRIPTIVE GEOMETRY USING GEOGEBRA

Aris Hadiyan Wijaksana¹, Yaya Sukjaya Kusumah², Turmudi³

^{1,2,3} Universitas Pendidikan Indonesia, Jawa Barat, Indonesia
turmudi@upi.edu

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Abstract

Descriptive Geometry is a fundamental course that demands high-level spatial visualization skills, where students often face significant cognitive challenges in projecting three-dimensional (3D) objects onto two-dimensional (2D) planes using conventional methods. This study aims to deeply explore student perceptions regarding the use of the dynamic geometry software GeoGebra as a medium for visualizing abstract concepts in this course. Using a qualitative case study approach, this research involved 13 students from the mathematics education program at Universitas Negeri Jakarta. Data were collected through semi-structured interviews and analyzed using thematic analysis. The findings indicate that students perceive GeoGebra as a transformative pedagogical tool. Four main themes were identified: (1) GeoGebra serves as a conceptual bridge that translates abstract concepts into concrete and dynamic visual representations; (2) GeoGebra's interactive environment is considered far superior to the static paper-and-pencil method, offering accuracy, efficiency, and freedom to experiment; (3) The use of GeoGebra shifts the student's role from a passive recipient to an active learner engaged in independent exploration; and (4) Despite an initial learning curve, the challenge of mastering the software fosters the development of student agency and learning autonomy. This study concludes that GeoGebra effectively reduces the cognitive load associated with spatial visualization and enhances student engagement and conceptual understanding. The implications of these findings underscore the importance of planned technological integration into advanced geometry curricula to facilitate more meaningful learning.

Keywords: Descriptive Geometry; GeoGebra; Spatial Visualization; Student Perceptions; Dynamic Geometry Software

INTRODUCTION

Descriptive Geometry is an essential branch of geometry that serves as a foundation for the development of spatial reasoning abilities in various disciplines, such as engineering, architecture, graphic design, and mathematics education (Baranová & Katreničová, 2018; Chivai et al., 2022). The core of this course is the representation of three-dimensional (3D) objects on a two-dimensional (2D) plane through systematic projection methods. However, behind its fundamental role, Descriptive Geometry presents inherent cognitive challenges. Students are required to perform a series of complex mental operations, including rotation, translation, and depth perception, to accurately visualize the spatial relationships between objects and their projections (Chivai et al., 2024). A study

conducted by Baranová & Katreničová (2018) confirmed that although the Descriptive Geometry course has been shown to have a positive impact on the development of spatial skills, it is often considered one of the most difficult subjects by students.

Historically, the pedagogy of Descriptive Geometry has heavily relied on conventional paper-and-pencil methods. Students use tools such as rulers, compasses, and protractors to manually draw projections. Although this method trains precision and procedural understanding, it has significant limitations. Its static nature renders visual representations rigid and non-manipulable. This limitation forces students to rely purely on imagination to visualize 3D objects, a process that is highly cognitively demanding. As one student in this study expressed, manual drawing is not only "difficult

if drawn manually" but also highly prone to errors, where "manual errors are very likely to occur" and "even a small mistake might be difficult to correct, especially if the drawing is quite complex". This limitation aligns with the argument that static illustrations in textbooks or on a blackboard fail to present the dynamic processes required for the complete construction of geometric concepts (Hohenwarter & Jones, 2007).

The development of educational technology in recent decades has introduced potential solutions to overcome these challenges through Dynamic Geometry Software (DGS). One of the most prominent and widely adopted DGS is GeoGebra. GeoGebra is an interactive mathematics software that integrates geometry, algebra, calculus, and statistics into a single, intuitive, and accessible platform (Batiibwe, 2024; Kusnadi & Asih, 2023). Its most fundamental capability is providing dynamically linked multiple representations; changes made to the geometric representation are automatically reflected in its algebraic representation, and vice versa. This feature makes GeoGebra a powerful tool for visualizing abstract mathematical concepts, transforming them into digital objects that can be manipulated, explored, and analyzed by the user (Kusnadi & Asih, 2023; Tang & Nguyen, 2025).

Although many quantitative studies have demonstrated the positive impact of GeoGebra on academic achievement and students' spatial visualization abilities (Güven & Kosa, 2008), a gap remains in the deep qualitative understanding of the student experience. How do students personally interpret the use of GeoGebra in the challenging context of Descriptive Geometry? How are their cognitive processes in understanding projection concepts facilitated by specific software features? What challenges do they face, and what strategies do they develop to overcome them? Research in education increasingly recognizes the importance of exploring student perspectives to gain a rich and contextual understanding of the effectiveness of a pedagogical intervention (Saputra, 2016).

Therefore, this study aims to answer these questions by analyzing the perceptions and experiences of 13 students from the Mathematics

Education Study Program at Universitas Negeri Jakarta in using GeoGebra in the Descriptive Geometry course. This study is expected to provide deep insights into the mechanisms behind GeoGebra's effectiveness and offer practical implications for the teaching of advanced geometry in higher education.

METHOD

Research Design

This study employed a qualitative approach with a case study design. This design was chosen for its relevance in conducting an in-depth investigation of a contemporary phenomenon within its specific real-life context. In this study, the phenomenon under investigation is the students' experiences and perceptions of using GeoGebra in the Descriptive Geometry course. The case study approach allows the researcher to gain a holistic and richly detailed understanding of how students interact with the technology, make sense of the learning process, and articulate the benefits and challenges they encounter.

Participants and Context

The participants in this study were 13 students enrolled in the Mathematics Education Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Jakarta. The research was conducted during the spring semester of the 2024/2025 academic year within the scope of the Descriptive Geometry course.

To ensure the collection of highly relevant and in-depth data, participants were deliberately selected using a purposive sampling technique based on strict academic inclusion criteria. The primary criterion required students to be actively enrolled in the Descriptive Geometry course where GeoGebra was utilized as the primary learning medium. Furthermore, to guarantee that participants possessed a solid foundational understanding of spatial properties before engaging with the cognitive complexities of 3D-to-2D projections, they were required to have successfully completed the prerequisite courses of "Euclidean Geometry" and "Solid Geometry" in the preceding semesters. Notably, having completed the Solid Geometry course, these participants had already acquired basic

proficiency in operating GeoGebra. This specific criterion ensures that any cognitive challenges observed in this study were genuinely related to spatial projection difficulties rather than basic software navigation hurdles.

The final sample size of 13 participants was determined based on the qualitative principle of *data saturation*. The researcher concluded the sampling process when the collected data became saturated, meaning no new significant themes or pedagogical perspectives emerged from the in-depth interviews. All participants provided explicit consent to participate, and their identities were anonymized in this report using codes S1 to S13 to maintain strict confidentiality

Research Procedure

To ensure a systematic and transparent investigation, the research activities were conducted through four sequential phases:

1. **Preparation Phase:** The researcher designed specific instructional scenarios for the Descriptive Geometry course that fully integrated GeoGebra-enhanced learning. Concurrently, a semi-structured interview protocol was developed and validated, specifically tailored to explore students' spatial projection abilities and their cognitive experiences when transitioning from 3D objects to 2D planes.
2. **Implementation Phase:** The GeoGebra-assisted instructional design was enacted during the teaching and learning process of the Descriptive Geometry course. Throughout this phase, students actively engaged in hands-on activities, utilizing the dynamic software to construct, manipulate, and analyze complex geometric projections, shifting away from traditional static visualization methods.
3. **Data Collection Phase:** Following the implementation, in-depth, semi-structured interviews were conducted with the 13 selected participants. The interviews were carefully directed to capture their retrospective reflections on the learning process, focusing on how the

software influenced their spatial visualization and cognitive load.

4. **Data Analysis Phase:** The qualitative data obtained from the audio-recorded interviews were transcribed verbatim and subjected to rigorous thematic analysis. The data were systematically coded to identify recurring patterns and meaningful pedagogical implications, which were subsequently categorized into the central themes discussed in this study.

Data Collection

Primary data were collected through semi-structured interviews. An interview protocol consisting of 11 open-ended primary questions was developed to guide the discussions. These questions were designed to explore various aspects of the students' experiences, including: (1) their initial motivation for using GeoGebra, (2) concrete experiences in the course, (3) understanding of projection concepts with the aid of the software, (4) difficulties encountered and strategies to overcome them, (5) perceptions of GeoGebra's usefulness for other students, (6) the most beneficial features, (7) experiences with personal projects, (8) comparisons with conventional methods, (9) impact on learning engagement, (10) advantages and disadvantages, and (11) suggestions for future development. Interviews were conducted in a conducive atmosphere to encourage participants to provide honest and detailed responses.

Data Analysis

All recorded interview data were transcribed verbatim to ensure accuracy. Transcript data were then analyzed using thematic analysis. This analysis process was carried out through several systematic stages: (1) *Data familiarization*, where the researcher repeatedly read all transcripts to gain a comprehensive understanding; (2) *Initial coding*, the process of identifying and labeling data segments relevant to the research questions; (3) *Searching for themes*, where similar codes were grouped into potential themes; (4) *Reviewing themes*, the process of validating and refining the formed themes to ensure internal coherence and

distinction from other themes; and (5) *Defining and naming themes*, the finalization stage where each theme was given a representative name and clearly defined. This systematic analysis process ensures that the findings are genuinely rooted in the empirical data and authentically reflect the voices of the participants.

RESEARCH RESULTS AND DISCUSSION

Thematic analysis of the interview data yielded four interconnected main themes that

comprehensively describe the students' perceptions of using GeoGebra in the Descriptive Geometry course. These themes are: (1) Dynamic visualization as a conceptual bridge from abstract to concrete; (2) The superiority of the interactive environment, surpassing the limitations of conventional methods; (3) The transformation of the student's role from passive recipient to active explorer; and (4) The learning curve paradox as both a hindrance and a catalyst for student agency.

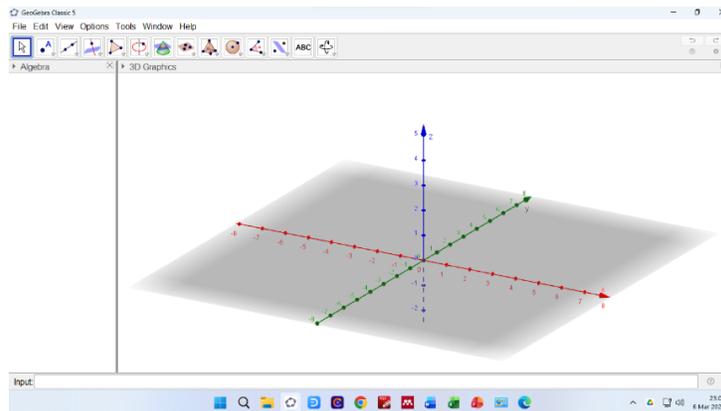


Figure 1. 3D Graphics View in GeoGebra

Dynamic Visualization as a Conceptual Bridge: From Abstract to Concrete

The most dominant and consistent theme among all participants was the role of GeoGebra in transforming the abstract concepts of Descriptive Geometry into concrete and easily understandable visual representations. Students repeatedly emphasized how GeoGebra's ability to model objects in three-dimensional (3D) space and dynamically project them onto a two-dimensional (2D) plane was key to their understanding. The "3D Graphics View" feature (Figure 1) was cited as the most transformative element. One student (S2) stated, "My interest... was to make learning more effective in visualizing abstract concepts like projections, intersecting planes, and spatial relationships that are difficult to grasp through verbal explanations alone. With GeoGebra, it's easy to create interactive visualizations, making these concepts more concrete". This statement was reinforced by S5, who mentioned that "...the 2D and 3D views make visualization interactive, so concepts that were initially abstract become easier to

understand". The ability to better imagine spatial objects was also highlighted by S11, "The 3D feature in GeoGebra also makes it easier for me to imagine the spatial figures in Descriptive Geometry". Furthermore, S12 added that complex visualization processes such as "...transformations of spatial objects, orthogonal projections, or intersections of planes and solids can be visualized with ease".

To facilitate this dynamic transition from abstract spatial ideas to concrete planar representations, the researcher developed specific interactive instructional instruments using GeoGebra. Figure 2 illustrates one of these developed instruments, designed specifically for the orthographic projection module. Unlike static textbook diagrams, this instrument features a dual-window interface that synchronously links a 3D graphics view of a pyramid on the right with its corresponding 2D horizontal projection (XY plane) on the left. Furthermore, the instrument incorporates dynamic tools—specifically, a slider that allows students to continuously alter the base edge length of the pyramid. As students interact

with this slider, they can immediately observe the concrete 2D consequences of their 3D manipulations in real-time. This specific interactive design serves as the actual conceptual bridge; it enables students to actively manipulate variables and confirm their spatial hypotheses dynamically, transforming abstract geometric properties into observable phenomena.

Superiority of the Interactive Environment: Surpassing the Limitations of Paper and Pencil

Students explicitly compared the learning experience using GeoGebra with conventional methods and concluded the superiority of the interactive digital environment. This comparison centered on three main aspects: accuracy, efficiency, and flexibility for exploration. The paper-and-pencil method was

described as slow, rigid, and prone to errors that are difficult to correct. Student S9 highlighted the issue of accuracy, "In complex descriptive geometry drawings, manual errors are very likely. Using GeoGebra can help produce more accurate and precise drawings, reducing errors that could occur if made manually". The problem of efficiency and difficulty in revision was also expressed by S10, who stated, "...if a manual drawing is slightly wrong, it might be difficult to correct, especially if the drawing is quite complex". Moreover, S8 emphasized the limitation of static media in facilitating a holistic understanding: "Conventional methods have limitations in viewing a plane or space from all directions or sides. Whereas with GeoGebra, the constructed figure can be observed flexibly...".

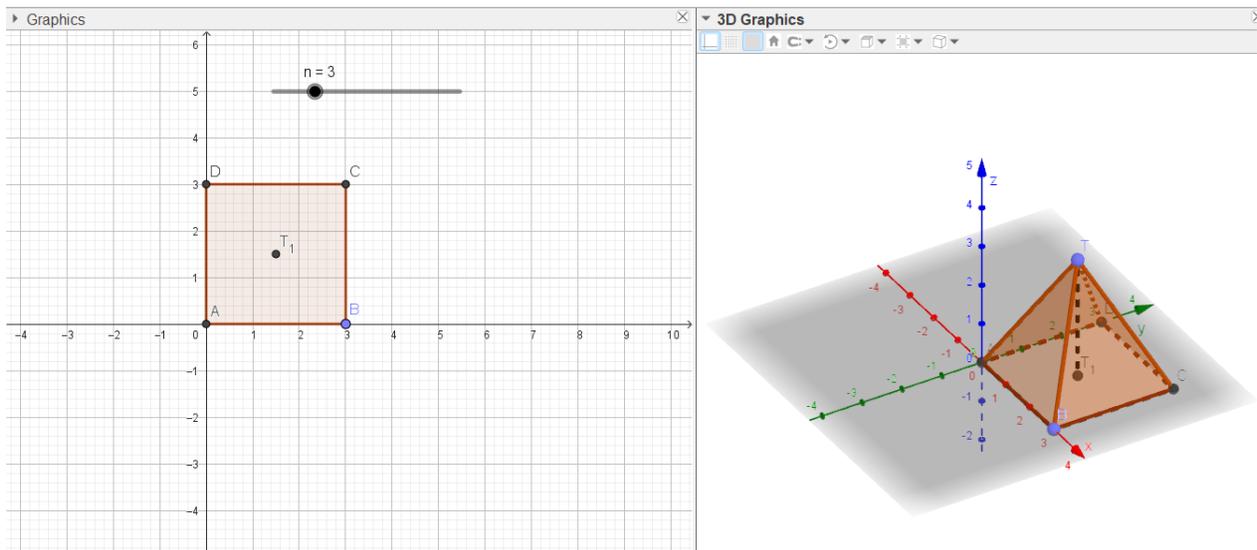


Figure 2. The interface features a synchronized dual-view displaying a 3D pyramid (right) and its 2D projection on the XY plane (left)

From Passive Recipients to Active Explorers: Enhanced Student Engagement

The use of GeoGebra fundamentally changed the learning dynamics and the position of students in the process. A strong theme that emerged from the interview data was how the software encouraged a shift from passive learning—where students merely receive information from the lecturer—to active learning centered on exploration and discovery. GeoGebra's interactive environment invited

students to "play" with geometric concepts. A sense of direct involvement was expressed by S6, who described the experience as "...fun because I became active and interacted directly through GeoGebra". Another important aspect was the learning environment free from the fear of making mistakes. Student S9 explained, "GeoGebra allows students to experiment with geometric concepts without fear of making mistakes. They can easily change variables, move points, or try different perspectives. This free

exploration encourages creativity and curiosity...". This transformation in the learning approach was well summarized by S12: "...this platform changes the learning approach from passive to interactive, allowing for more engaging and intuitive exploration of concepts".

The Learning Curve Paradox: An Obstacle and a Catalyst for Student Agency

Although the benefits of GeoGebra were strongly felt, the students' experience was not entirely seamless. A theme that provided a balanced perspective was the challenge related to the learning curve in mastering the software. Students reported initial difficulties in understanding the interface and the functions of the various tools available. What is interesting, however, is how they overcame these challenges,

which in turn demonstrated the development of agency and learning autonomy. Initial difficulties were voiced by S1, "Difficulty in using features or tools because not all tools are introduced in a course". S8 also described the challenge of following the lecturer's instructions in real-time: "...I need to focus when the lecturer is explaining because, for instance, I might be slow in following the lecturer's explanation while drawing using GeoGebra...". However, instead of giving up, students proactively sought solutions. S2 explained his strategy, "...I utilized online tutorials, learning videos, and GeoGebra user forums". Collaboration with peers also became a key strategy, as stated by S9, "Of course, I would watch tutorials on YouTube, but if the difficulty persisted, I decided to discuss it with a classmate. That was very helpful for me...".

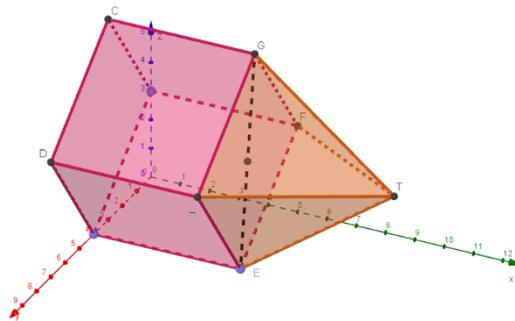


Figure 3. The concrete 3D representation of a composite geometric solid (a combined cube and pyramid) as visualized in the GeoGebra 3D Graphics view.

The findings from the interview data provide deep insights into the cognitive and pedagogical mechanisms behind GeoGebra's effectiveness in the context of Descriptive Geometry. This discussion will elaborate on each theme by connecting it to relevant theoretical frameworks and literature.

GeoGebra as a Cognitive Bridge

To explicitly demonstrate how GeoGebra functions as a cognitive bridge in this research, Figures 2 through 5 illustrate a specific instructional example involving the orthogonal projection of a composite 3D solid (a combined cube and pyramid). In traditional learning environments, students must rely purely on abstract mental rotation to translate a concrete 3D object (Figure 3) into 2D planes, a process that frequently induces cognitive overload.

However, by utilizing GeoGebra's "View in front of" feature, the software actively bridges this epistemic gap. Students can systematically and instantaneously decompose the complex 3D volume into its precise 2D planar representations: the horizontal projection on the XY plane (Figure 4), the frontal projection on the XZ plane (Figure 5), and the profile projection on the YZ plane (Figure 6). This interactive decomposition acts as a tangible cognitive bridge; it externalizes the abstract mental transformation process, allowing students to directly observe, manipulate, and verify the mathematical connection between a spatial configuration and its corresponding orthogonal projections (Suparman et al., 2024; Tang & Nguyen, 2025). Rather than merely guessing the outcome of a mental rotation, students use the software to physically anchor their spatial reasoning.

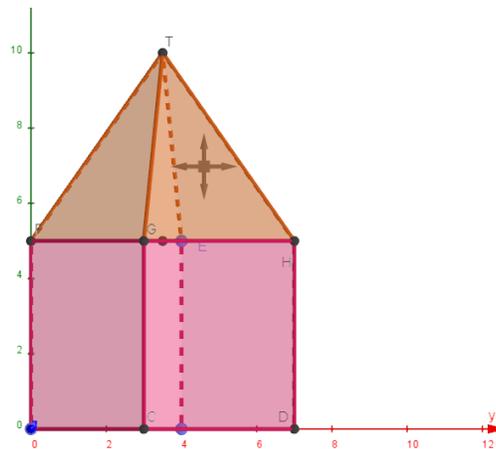


Figure 4. The 2D orthogonal projection of the composite solid onto the XY plane.

The finding that GeoGebra functions as a bridge from abstract concepts to concrete representations highlights its role as a cognitive mediator. Students often struggle to validate the correctness of the 2D projections they create manually because there is no certain way to know if their spatial imagination is accurate. GeoGebra addresses this by providing an interactive feedback loop. As explained by S11, "when I was confused by the two-dimensional drawing, I could also see the 3D drawing, so the projection was easier to imagine". The 3D view serves as a visual "answer key" that allows instant verification. This process not only corrects misconceptions in real-time but also builds

students' confidence. This bridge between 2D and 3D representations effectively reduces the cognitive load associated with purely imaginative visualization, consistent with studies showing that GeoGebra significantly promotes spatial visualization ability (Ridwan, 2024) and helps students move beyond the limitations of static representations for deeper conceptual understanding (Hohenwarter & Jones, 2007; Suparman et al., 2024). The ability to manipulate objects and view them from various angles is a fundamental advantage of DGS that cannot be replicated by static media (Gülburnu, 2025; Maričić et al., 2025).

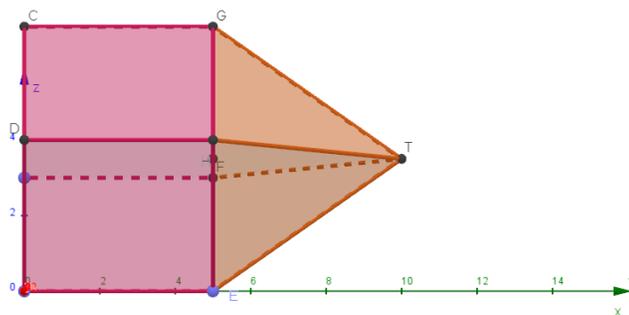


Figure 5. The 2D orthogonal projection of the composite solid onto the XZ plane.

Cognitive Offloading

The superiority of GeoGebra's interactive environment can be explained through the concept of cognitive offloading. Drawing projections manually demands a significant allocation of cognitive resources to mechanical

tasks (precision, scale, neatness). This burden leaves little mental capacity to focus on conceptual understanding. GeoGebra automates these mechanical tasks, freeing up students' working memory capacity to concentrate on the conceptual aspects. Their focus shifts from "how

do I draw this correctly?" to "why does this projection look like this?". This phenomenon is in line with theoretical frameworks that identify the role of technology as an "amplifier" that enables more efficient task completion

(Suparman et al., 2024). The "drag mode" feature is particularly recognized as a powerful problem-solving tool, allowing for experiments that are impossible with static media (Suparman et al., 2024; Zengin, 2017).

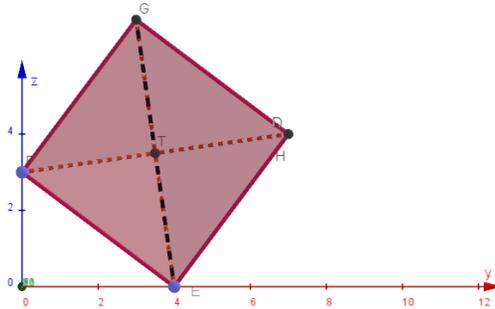


Figure 6. The 2D orthogonal projection of the composite solid onto the YZ plane.

Constructivism and Inquiry-Based Learning

The shift from passive to active learning signifies the adoption of an inquiry-based mindset. The ability to manipulate objects, undo actions, and see visual consequences instantly transforms the learning process into an investigation. Students can independently pose exploratory questions ("What happens if..") and immediately receive visual feedback. This turns the classroom into a virtual laboratory for geometric experimentation, which aligns perfectly with constructivist learning theory, where knowledge is actively constructed by the learner through interaction with their environment. The literature supports this finding, identifying GeoGebra as an effective tool for motivating and enhancing active student engagement (Kusnadi & Asih, 2023), as well as fostering the processes of exploration and conjecture-making that are the foundation of mathematical reasoning (Gülburnu, 2025; Zengin, 2017).

Student Agency and the Role of the Educator

While GeoGebra significantly enhances student agency by shifting their role from passive recipients to active explorers, the qualitative findings reveal that this transition is not entirely autonomous. The interactive environment evidently cultivates self-efficacy and motivates independent problem-solving (Ridwan, 2024; Saputra, 2016). However, the initial learning curve associated with the software introduces a

critical pedagogical tension. If not properly managed, the technical demands of navigating the 3D-to-2D interface can impose a high extraneous cognitive load, potentially overshadowing the germane cognitive processes required for geometric reasoning (Suparman et al., 2024). This phenomenon underscores the indispensable role of the educator in orchestrating a technology-enhanced learning environment. Drawing upon the concepts of *didactical orchestration* and *scaffolding*, the lecturer must deliberately design instructional tasks that minimize unproductive technical struggles. The educator acts as a vital facilitator who guides the process of *instrumental genesis*—ensuring the software transforms from a mere digital drawing tool into a profound cognitive instrument for spatial reasoning, rather than a space for aimless trial-and-error (Widder & Gorsky, 2013). Ultimately, the data strongly suggest that technological integration alone does not guarantee comprehension; it is the highly structured pedagogical guidance that prevents students from fixating on procedural software operations, actively directing their cognitive resources toward grasping the underlying Descriptive Geometry principles.

CONCLUSION

This research, through an in-depth analysis of the perceptions of 13 students, confirms that GeoGebra serves as a highly effective pedagogical tool in addressing the

visualization challenges inherent in the Descriptive Geometry course. The main findings indicate that students view GeoGebra not merely as a digital substitute for paper and pencil, but as a transformative learning environment. The software acts as a vital conceptual bridge, translating abstract geometric ideas into dynamic and concrete visual representations, thereby making them more accessible and understandable. The superiority of GeoGebra's interactive environment, which allows for manipulation, error-free experimentation, and instant verification, effectively offloads the cognitive burden from mechanical tasks to higher-level conceptual understanding. Consequently, a fundamental shift occurs in the student's role, from a passive recipient of information to an active and engaged explorer of knowledge.

The practical implications of these findings are significant for geometry instruction at the university level. The results of this study provide a strong argument for systematically integrating GeoGebra into the Descriptive Geometry curriculum. However, its implementation must be done with pedagogical awareness. GeoGebra should be positioned as a complementary tool to enrich understanding, not as a total replacement for fundamental geometric reasoning. Educators need to design tasks that are structured yet open to exploration, explicitly encouraging students to reflect on the "why" behind the resulting visualizations, not just the "what" is seen on the screen. Given the learning curve, providing support resources such as video tutorials and facilitating collaborative learning sessions can help students overcome initial technical hurdles more efficiently, as suggested by the participants.

This qualitative case study provides deep but context-specific insights. Therefore, several directions for future research can be recommended. First, quantitative or mixed-methods research could be conducted to objectively measure the impact of GeoGebra use on students' spatial reasoning ability test scores and academic achievement. Second, based on suggestions from students (S2, S5), developmental research could focus on designing and testing interactive GeoGebra-based learning

modules specifically tailored for topics in Descriptive Geometry. Third, a comparative study could explore the effectiveness of different DGS platforms. Lastly, as technology advances, future research could investigate the potential of integrating more immersive technologies such as augmented reality (AR) or virtual reality (VR), as proposed by S12, to create even more profound and intuitive spatial visualization learning experiences.

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