



Immersive Technologies in Education 4.0: Improving Spatial Visualization in Orthogonal Projections and Cylindrical Sections Using GeoGebra and Qubism 3D Modeling

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ABSTRACT

In the context of Education 4.0, General Secondary Education in Mozambique faces challenges in integrating digital technologies, with teaching practices still largely traditional. This study analyses the contribution of digital tools, namely GeoGebra and Qubism 3D Modeling, to the development of spatial visualization skills in Orthogonal Projections and Cylindrical Sections. Framed within smart learning ecosystems, the research adopted a quasi-experimental design with mixed methods, involving 165 students divided into experimental and control groups. The findings show that the integration of immersive technologies and active methodologies led to significant improvements in academic performance and three-dimensional spatial visualization. Data analysis, supported by learning analytics practices, revealed substantial gains in the experimental group. The study concludes that the incorporation of digital tools enhances adaptive personalization and highlights the need to strengthen teacher digital literacy, as well as educational governance, in alignment with the demands of Industry 4.0.

Keywords: qubism 3d modeling; geogebra; orthogonal projections; cylindrical sections; education 4.0; immersive technologies; spatial visualization

INTRODUCTION

In Mozambique, the integration of Information and Communication Technologies (ICT) into teaching practices remains limited, a situation that is particularly concerning in the context of the Fourth Industrial Revolution. Driven by the rapid evolution of artificial intelligence, mobile computing, the Internet of Things, and three-dimensional environments, this transformation requires education systems to develop skills such as critical

thinking, creativity, problem-solving, and digital literacy (Schwab, 2023). In this context, education plays a strategic role in preparing citizens capable of responding to the challenges of an increasingly digitized society.

UNESCO (2023) argues that education systems should promote digital competencies and lifelong learning. However, many countries, especially developing ones, continue to face difficulties in effectively integrating ICT. Furthermore, simply making technological resources available does not guarantee improved learning; it is essential to adopt student-centered methodologies that foster active participation, collaboration, and knowledge construction (Selwyn, 2022).

Despite these guidelines, the teaching of Technical Drawing and Descriptive Geometry in general secondary education in Mozambique continues to rely on traditional methodologies, predominantly using blackboards and conventional drawing instruments. This situation is exacerbated by infrastructure limitations, limited Internet access, and restrictions on the use of smartphones in school settings, hindering the pedagogical integration of ICT. Although the Government of Mozambique has implemented initiatives such as GovNet, SchoolNet Mozambique, and MoRENet, as well as curriculum reforms that include ICT, the use of technology remains frequently limited to digital literacy and distance learning, with interactive applications that enhance the understanding of scientific content being underutilized. This scenario reveals a gap between current educational practices and the competencies required by Industry 4.0.

Several studies demonstrate that digital technologies promote student engagement, personalized learning, and the development of spatial visualization. Artificial intelligence enables the provision of adaptive feedback tailored to students' individual needs (Selamet, 2026). In turn, augmented reality improves spatial visualization and motivation in STEM subjects (Ibáñez & Delgado-Kloos, 2018), while three-dimensional modeling facilitates the understanding of complex spatial relationships and fosters essential skills for the digital age (Zeng et al., 2025).

In the Mozambican context, many students struggle with spatial visualization, particularly when transforming three-dimensional objects into two-dimensional representations, which hinders their learning of orthogonal projections and cross-sections of cylinders. These difficulties justify the adoption of pedagogical strategies supported by digital technologies that facilitate the manipulation and exploration of three-dimensional models. Within this framework, the present study analyzes the potential of the Qubism 3D Modeling and GeoGebra apps, used on smartphones, in developing the spatial visualization skills of students in general secondary education. The research seeks to answer the following question: How does the use of the Qubism 3D Modeling and GeoGebra apps on smartphones contribute to the development of spatial visualization and to students' ability to transform three-dimensional objects into two-dimensional representations when studying orthogonal projections and cross-sections of cylinders?

TECHNOLOGICAL APPLICATIONS

Technological applications have become increasingly relevant in education by making teaching and learning processes more dynamic, interactive, and engaging. Their integration into pedagogical practices promotes participatory learning environments, allowing students and teachers to explore concepts through multiple representations and interactions (Zeng et al., 2025). These tools support the diversification of teaching strategies by transforming abstract concepts into practical experiences through simulations, digital modelling, and collaborative activities. Additionally, they enable the creation of accurate and detailed three-dimensional representations, facilitating the understanding of complex phenomena and the relationship between mental and graphical representations.

In this study, two applications were selected: Qubism 3D Modeling (Q3DM), version 0.9.6, and GeoGebra, version 5.0.721.0, both adapted for smartphones. These tools were chosen due to their potential to support geometric learning and develop spatial visualization skills. Their interactive and student-centred features align

with Education 4.0 principles, enabling the manipulation of 3D objects, exploration of geometric properties, and observation of solids from different perspectives. Consequently, they contribute to spatial reasoning, problem-solving, and conceptual understanding, which are essential competencies in STEM education. However, the use of technology in Technical Drawing and Descriptive Geometry requires careful pedagogical integration, as digital tools alone do not guarantee learning improvements. According to Lvovna and Shagiyazovna (2023) and Valiyev et al. (2023), the effectiveness of digital resources depends on appropriate planning, with the teacher playing a central role in defining objectives and guiding learning activities. Without proper integration, technological resources may cause distraction, increase dependence on digital devices, and reduce opportunities for developing traditional graphic skills.

The main limitations identified include students' access to unrelated online content, excessive dependence on digital resources, and visual fatigue from prolonged screen use, reduced practice of manual drawing, limited functionalities in some 3D applications, and possible inaccuracies in orthographic representations caused by inappropriate perspective effects. Therefore, digital applications should not replace traditional teaching methods but rather complement them. In Technical Drawing and Descriptive Geometry, this integration is particularly important because spatial visualization requires the connection between 3D models, 2D representations, and conventional graphic procedures. Despite these limitations, tools such as Q3DM and GeoGebra provide valuable learning opportunities by enabling virtual manipulation of geometric objects, exploration of spatial configurations, and improved understanding of abstract concepts.

Thus, the balanced integration of technological applications contributes to Education 4.0 by promoting more interactive and competency-based learning environments. When supported by appropriate pedagogical strategies, technology acts as a mediator in knowledge construction and in the development of students' spatial visualization abilities.

COMPUTER SIMULATIONS, IMMERSIVE LEARNING ENVIRONMENTS

Computer simulations have become increasingly important in STEM education, where understanding abstract concepts, solving complex problems, and developing spatial visualization skills pose significant challenges. In the context of the Fourth Industrial Revolution, these technologies have evolved into immersive learning environments that integrate three-dimensional modeling, virtual reality, augmented reality, and dynamic geometry software. These environments promote more interactive, exploratory, and student-centered learning, emphasizing experimentation and the active construction of knowledge.

In the teaching of Technical Drawing and Descriptive Geometry, computer simulations are particularly important due to the abstract nature of the subject matter. Manipulating three-dimensional models, observing geometric transformations in real time, and exploring different orthogonal views facilitate an understanding of the relationships between three-dimensional objects and their two-dimensional representations. Three-dimensional visualization technologies also contribute to the development of spatial reasoning, an essential skill in STEM fields and in areas such as engineering, architecture, design, and digital technologies (Zeng et al., 2025). Recent studies also show that combining computer simulations with immersive environments enhances the learning of abstract concepts, allowing students to establish connections between different forms of representation and overcome the limitations of static two-dimensional images (Blake & Hunter, 2023). From this perspective, digital environments function as cognitive mediators, facilitating the construction of more structured mental models. From a constructivist perspective, these technologies promote learning through interaction, experimentation, and reflection. By manipulating digital objects, testing hypotheses, and analyzing the results of their actions, students actively participate in the construction of knowledge, in line with the principles of active learning.

Immersive learning environments also foster autonomy, collaboration, critical thinking, creativity, and problem-solving skills that are essential in STEM education and particularly valued in Industry 4.0 (Gegenfurtner & Kollar, 2024). However, their educational impact depends on how they are integrated into teaching practices, since technology alone does not guarantee better learning outcomes. Thus, the effectiveness of computer simulations depends on their pedagogical integration, teacher preparation, and the alignment of activities with learning objectives. In the teaching of Technical Drawing and Descriptive Geometry, these tools complement traditional methods, promoting conceptual understanding, the development of spatial reasoning, and more meaningful learning, thereby preparing students for the scientific and technological challenges of the digital society.

Three-Dimensional Spatial Visualization

Three-dimensional spatial visualization is an essential cognitive skill in STEM fields, enabling individuals to mentally form, manipulate, and interpret three-dimensional objects, as well as to understand their shapes, orientations, and spatial relationships. It is particularly important in Descriptive Geometry, Technical Drawing, Architecture, and Engineering, where the conversion between two-dimensional and three-dimensional representations is an indispensable skill. In addition to geometric perception, it involves reasoning, abstraction, and mental representation skills that are fundamental to solving technical and scientific problems.

The literature identifies spatial visualization as one of the main predictors of academic and professional success in technical and scientific fields. Bairaktarova and Cohen (2023) note that this skill can be assessed using specific instruments, such as the Santa Barbara Solids Test, which allows for the analysis of the ability to mentally visualize, interpret, and transform three-dimensional objects, as well as to identify individual differences in tasks involving mental rotation and the manipulation of solids.

Technical Drawing and Descriptive Geometry

Three-dimensional spatial visualization is a fundamental cognitive skill in STEM fields, as it enables students to mentally form, manipulate, transform, and interpret three-dimensional objects, understanding their shapes, orientations, and spatial relationships. This skill is particularly relevant in the teaching of Descriptive Geometry, Technical Drawing, Architecture, and Engineering fields in which the interpretation of and conversion between two-dimensional and three-dimensional representations are constant requirements of the learning process. In this context, spatial visualization is not limited to the geometric perception of objects; it also involves reasoning, abstraction, and mental representation skills that are indispensable for solving technical and scientific problems. The specialized literature recognizes spatial visualization as one of the most important cognitive abilities for academic and professional success in technical and scientific fields. This skill can be assessed using specific instruments that allow for the identification of individual differences in student performance, particularly in tasks related to mental rotation, the manipulation of geometric solids, and the understanding of complex spatial relationships (Bairaktarova & Cohen, 2023). The authors highlight the Santa Barbara Solids Test as a valid and effective tool for assessing the ability to mentally visualize, interpret, and transform three-dimensional objects, allowing for a more in-depth analysis of the development of spatial skills.

In recent decades, numerous studies have shown that spatial visualization is not an innate and immutable ability but can be developed through appropriate pedagogical strategies and the use of technological resources. In this context, three-dimensional modeling activities, computer simulations, augmented reality, virtual reality, and interactive digital environments have demonstrated great potential for strengthening students' spatial skills. 3D visualization technologies contribute significantly to the development of spatial reasoning, facilitating the understanding of complex geometric concepts and improving academic performance in STEM subjects (Zeng et al., 2025). This perspective reinforces the idea that digital technologies can act as mediators of cognitive development, making content traditionally considered abstract more

accessible. The importance of spatial visualization becomes even more evident in the teaching of Descriptive Geometry and Technical Drawing, subjects that require students to be able to interpret different views of an object, identify geometric relationships, and transform three-dimensional representations into two-dimensional projections and vice versa. Difficulties with these skills can hinder the learning of content related to orthogonal projections, sections, intersections, and the graphical representation of geometric solids. Consequently, the development of spatial visualization is a fundamental requirement for success in these areas of knowledge.

Thus, spatial visualization is understood in this study not only as an essential cognitive skill for learning geometric content but also as a skill that can be developed through the integration of digital technologies and innovative teaching methodologies. From this perspective, the use of interactive three-dimensional environments and digital applications can play a significant role in strengthening students' spatial skills, while simultaneously contributing to more meaningful learning and the development of skills aligned with the educational and professional demands of Industry 4.0.

METHODOLOGY

This article presents a case study conducted over two years at a secondary school in southern Mozambique. Part of the data used comes from Chivai (2024) doctoral thesis, while the remainder stems from a new qualitative analysis based on Bardin (2016) content analysis developed specifically for this article. This analysis aimed to deepen the interpretation of the data and generate new evidence aligned with the research objectives. The study adopted a quasi-experimental design, as it was conducted in a real classroom setting and involved comparison groups subjected to different pedagogical strategies. Quasi-experimental studies differ from traditional experimental designs in that they do not allow for absolute control over intervening variables, particularly regarding participant randomization and the allocation of subjects to groups (Dutra & Reis, 2016). This approach is suitable for educational contexts, where limitations inherent to school organization and class composition hinder the implementation of fully controlled experimental designs. In educational contexts, this approach proves particularly suitable, given the constraints inherent in school organization, class composition, and existing pedagogical conditions. A total of 165 students participated in the study, divided into an experimental group and a control group. The groups were formed based on pre-existing classes, without involving individual random selection, corresponding to a cluster sampling strategy. This approach allowed for the preservation of the natural class organization and ensured greater ecological validity of the results. Although it limits control over some external variables, this procedure is appropriate for educational research conducted in real-world learning environments. The study involved three pedagogical interventions focused on the topics of Orthogonal Projections and Cross-Sections of Solids. In the experimental group, the digital technologies Qubism 3D Modeling (Q3DM) and GeoGebra were used to support the teaching and learning process, while in the control group, conventional methodologies based on the blackboard, printed materials, and hand-drawn diagrams were employed. Both groups underwent equivalent assessments and followed similar data collection procedures, allowing for a comparison of the results.

The study adopted a mixed-methods approach, integrating quantitative and qualitative procedures. This approach enables the combination of different forms of data collection and analysis, providing a broader understanding of educational phenomena (Creswell & Creswell, 2018). In this context, it allowed for an evaluation of the effects of digital technologies on student performance and an understanding of the cognitive, behavioral, and pedagogical processes associated with the development of spatial visualization. The quantitative component focused on a comparative analysis of the results obtained by male and female students on the pre-tests and post-tests administered before and after each intervention. Differences related to gender, teaching methodology, and participation in the experimental and control groups were analyzed

based on the learning gains achieved. This analysis made it possible to assess the development of spatial visualization skills and understanding of the content on Orthogonal Projections and Cross-Sections of Solids.

The qualitative component focused on the behaviors and processes exhibited by students during instructional activities, considering aspects such as participation, engagement, autonomy, difficulties, and problem-solving strategies. This dimension complemented the quantitative results, allowing for an understanding not only of the effects of the interventions but also of the processes through which learning occurred. Although it was not possible to fully control all external variables, participant observation, the use of common assessment tools, and the triangulation of quantitative and qualitative data helped to strengthen the consistency and credibility of the results. This methodological approach enabled an integrated analysis of the relationship between digital technologies, teaching practices, and the development of students' spatial visualization skills.

Pedagogical Intervention

In the teaching and learning process, dynamic relationships are established between the teacher, students, content, and educational resources. The teacher acts as a mediator of learning, setting objectives, selecting strategies, and organizing instructional situations tailored to the students' characteristics, while students actively participate in the construction of knowledge through interaction with the available content and resources. Pedagogical practice involves a dialectical relationship between teaching and learning, in which cognitive development results from the interplay between teacher mediation, prior experiences, and students' active participation in the educational process (Libâneo, 2013).

Pedagogical interventions constituted the main source of quantitative and qualitative data collection, with participant observation used to monitor the learning process. During the activities, aspects such as students' interaction with technological resources, their exploration of geometric models, their completion of the assigned tasks, and the difficulties identified throughout the process were analyzed. **Table 1** presents a description of the interventions carried out, including the content covered, participants, resources used, and methodological procedures adopted.

During the instructional interventions, the experimental and control groups were kept separate, allowing for a comparison of the effects of the different teaching strategies. In the control group, the content was taught using traditional methods based on oral presentation, use of the blackboard, printed materials, and manipulation of physical geometric solids. This approach emphasized observation, the reproduction of procedures, and the completion of exercises, requiring students to develop greater abstract thinking skills and spatial imagination to understand geometric shapes, interpret views, and mentally visualize cross-sections and transformations of three-dimensional objects.

In the experimental group, the content was explored using the digital applications Qubism 3D Modeling (Q3DM) and GeoGebra, enabling direct interaction with three-dimensional models. Students were able to manipulate geometric objects, change perspectives, analyze orthogonal projections, and visualize cross-sections in real time, establishing clearer relationships between three-dimensional and two-dimensional representations. The integration of digital exploration and manual graphic representation created a more dynamic learning environment, promoting the understanding of geometric concepts, the development of spatial visualization, autonomy, and logical reasoning. These results corroborate the findings of Küçük and Gün (2023), which highlight the potential of interactive digital environments for learning geometry and developing spatial skills.

Table 1. Themes and titles of instructional interventions

Project (Title)	Topic	Grade	App
1st (Study 1 Q3DM)	Orthogonal Projections	9th	Qubism 3D Modeling
2nd (Study 2 Q3DM)	Orthogonal Projections	9th	Qubism 3D Modeling
3rd (GeoGebra Study)	Cross-Sections of Cylinders	12th	GeoGebra

Table 2. Emerging thematic categories in the experimental group

Thematic category	Observed indicators	Qualitative interpretation
Interaction with digital technology	Active use of Q3DM and GeoGebra	More dynamic and participatory learning
Development of spatial visualization	Improved interpretation of visualizations and sections	Strengthening spatial competencies
Active learning	Exploration and autonomous problem-solving	Meaningful construction of knowledge
Learner autonomy	Reduced dependence on the teacher	Greater confidence and independence
Motivation and engagement	High level of interest in the activities	Greater predisposition to learn

The use of digital technologies also allowed students to explore different forms of representation, test hypotheses, and construct knowledge through interaction with virtual models. Unlike exclusively traditional approaches, in which understanding certain concepts depends primarily on the individual's ability to create mental images, digital resources served as cognitive mediators, reducing difficulties with spatial interpretation and promoting learning experiences aligned with constructivist principles. The thematic analysis of the observation records identified categories related to students' active participation, engagement in tasks, autonomy in exploring digital models, and the development of spatial visualization skills in the experimental group (see [Table 2](#)).

In the thematic analysis of the control group, the data collected through participant observation revealed categories associated with learning that was more dependent on teacher mediation and the use of predominantly static resources, such as the blackboard, printed materials, and physical geometric models. The records indicated that students relied primarily on reproducing procedures presented by the teacher, interpreting conventional graphical representations, and using spatial imagination to understand three-dimensional objects, projections, and geometric cross-sections. Although this approach allowed the intended learning objectives to be achieved, there were fewer opportunities for independent exploration, experimentation, and dynamic manipulation of objects compared to the experimental group (see [Table 3](#)).

Comparing the emerging categories revealed differences between the groups. In the experimental group, active learning, autonomy, motivation, participation, and the development of spatial visualization stood out; these were fostered by interaction with digital 3D models, which allowed students to explore representations, test possibilities, and construct knowledge through experimentation. In the control group, lecture-based methodologies predominated, alongside a greater reliance on teacher guidance and difficulties in the spatial interpretation of geometric objects. Although traditional methodologies contribute to the systematization of content, limited interaction with dynamic resources can restrict the exploration and manipulation of geometric objects. In contrast, Q3DM and GeoGebra provided visual and manipulative experiences that fostered the construction of 3D mental images and an understanding of the relationships between different representations.

Table 3. Emerging thematic categories in the control group

Categoria temática	Indicadores observados	Interpretação qualitativa
Traditional lecture-based teaching	Predominance of teacher-led instruction	Teacher-centered learning
Spatial visualization difficulties	Common errors in interpreting views and projections	Limitations in spatial understanding
Dependence on the teacher	Constant need for faculty support	Shorter range
Procedural learning	Repetition of exercises and application of rules	Less in-depth conceptual understanding
Limited physical resources	Use of static visual materials	Reduced stimulation of learning

Content analysis enables the identification of meaning patterns within qualitative data and the systematic interpretation of complex educational phenomena (Bardin, 2016). In this study, the thematic analysis of observation records complemented the quantitative results from pre- and post-tests, demonstrating that digital technologies contributed to learning environments that were more interactive and conducive to the development of spatial visualization.

RESULTS

The purpose of the quantitative analysis was to evaluate changes in student performance on the pretests and posttests across the three studies, which involved Q3DM (in both studies) and GeoGebra as well as to compare the results of the experimental and control groups. Descriptive statistics were used, specifically mean, median, mode, and minimum and maximum values, to identify changes in performance and the magnitude of learning gains. The pretest was used to assess prior knowledge and establish a baseline for the groups' initial conditions, while the posttest allowed for the assessment of changes following the interventions (Direnga et al., 2018). The comparative analysis between the groups also revealed a more significant improvement in the experimental groups, providing quantitative evidence of the contribution of digital technologies to the learning of orthogonal projections and cross-sections of solids (see Tables 4, 5, 6, and 7).

Table 4. Pre-test and post-test scores for the control group regarding the use of Qubism 3D Modeling

Description	Case 1 (%)		Case 2 (%)	
	Pre-test (%)	Post-test (%)	Pre-test (%)	Post-test (%)
Average	41.8	42.6	38.6	36.6
Median	45.0	40.0	35.0	35.0
Mode	25.0	50.0	25.0	25.0
Minimum	25.0	25.0	25.0	25.0
Máximo	85.0	7.0	85.0	64.0

Table 5. Pre-test and post-test scores for the experimental group regarding the use of Qubism 3D Modeling

Description	Case 1 (%)		Case 2 (%)	
	Pre-test (%)	Post-test (%)	Pre-test (%)	Post-test (%)
	50.3	82.0	57.8	87.6
Average	55.0	85.0	70.0	85.0
Median	50.0	85.0	65.0	85.0
Mode	25.0	40.0	10.0	10.0
Minimum	90.0	95.0	85.0	90.0

Table 6. Pre-test and post-test classifications for the control group regarding the use of GeoGebra

Description	GeoGebra	
	Pre-test (%)	Post-test (%)
	27.6	34.2
Average	25.0	30.0
Median	30.0	25.0
Mode	10.0	15.0
Minimum	85.0	85.0

Table 7. Pre-test and post-test ratings of the experimental group regarding the use of GeoGebra

Description	GeoGebra	
	Pre-test (%)	Post-test (%)
	27.5	55.5
Average	30.0	14.5
Median	6.0	72.5
Mode	10.0	10.0
Minimum	65.0	95.0

Intervention Using Qubism 3D Modeling

The results presented in Tables 4 and 5 show substantial differences between the control and experimental groups in the two cases analyzed using Qubism 3D Modeling (Q3DM). In Case 1 of the control group, the mean increased from 41.8% on the pretest to 42.6% on the posttest, corresponding to a gain of only 0.8 percentage points. In Case 2, the mean decreased from 38.6% to 36.6%, equivalent to -2.0 percentage points. In contrast, the experimental groups showed gains of 31.7 percentage points in Case 1 and 29.8 percentage points in Case 2. This difference highlights a considerably more pronounced improvement among students who participated in the Q3DM intervention.

The progress observed in the experimental groups is also confirmed by measures of central tendency. In Case 1, the median rose from 55% to 85% and the mode from 50% to 85%, while in Case 2 the median increased from 70% to 85% and the mode from 65% to 85%. The convergence among the increases in means, medians, and modes suggests that the improvement was not limited to a few high-performing students but occurred relatively consistently across the distribution of results. This trend contrasts with the control groups, in which changes in means were small and, in Case 1, the median decreased from 45% to 40%.

The difference between the groups on the posttest is particularly significant. In Case 1, the experimental group's average score of 82.0% was 39.4 percentage points higher than the control group's average of 42.6%. In Case 2, the difference reached 51.0 percentage points, with 87.6% in the experimental group and 36.6% in the control group. Considering the progress between the two time points, the difference in gains was 30.9 percentage points in Case 1 and 31.8 percentage points in Case 2. These results provide consistent descriptive evidence of an association between the use of Q3DM and more favorable performance trends. The present study reinforces this evidence, since, in addition to the improvement in measures of spatial visualization, the academic grade results show a particularly large difference between students who used Q3DM and those who remained in the control group. The results are also consistent with Küçük Avcı et al. (2019), cited in the article, in that they highlight the importance of interactive three-dimensional environments for the development of spatial ability and the learning of geometry. From this perspective, the advantage observed in the experimental groups can be understood not only as a result of introducing a technological tool, but as a consequence of creating additional opportunities to explore spatial relationships, test representations, and observe different perspectives of the same object.

The difference between the groups can also be interpreted in light of Bairaktarova and Cohen (2023), who draw attention to the relationship between interactive spatial training and performance among engineering students. This perspective is particularly relevant to Descriptive Geometry, since mastery of orthogonal projections requires coordination between different perspectives of an object and the ability to establish correspondences between spatial and graphical representations.

Thus, the results of this study suggest that Q3DM may have functioned as a visual and manipulable mediator of learning, allowing students to virtually experience spatial relationships that, in exclusively conventional

instruction, must be mentally constructed from static drawings. This possibility may explain the difference observed between the groups, especially since the control group showed virtually no improvement, while the experimental groups showed gains of nearly 30 percentage points.

Intervention Using GeoGebra

The results in Tables 6 and 7 also reveal a more pronounced improvement in the experimental group than in the control group. In the control group, the mean increased from 27.6% to 34.2%, corresponding to a gain of 6.6 percentage points. Although this change represents a positive improvement, the magnitude is considerably lower than that observed in the experimental group, whose mean rose from 27.5% to 55.5%, corresponding to a gain of 28.0 percentage points.

The difference between the groups' gains was therefore 21.4 percentage points, while the difference between the post-test means reached 21.3 percentage points. These figures suggest a significant descriptive advantage for the group that used GeoGebra. The observed improvement is particularly relevant because the groups had virtually identical means on the pretest: 27.6% in the control group and 27.5% in the experimental group. Thus, in this case, the initial difference between the groups was practically nonexistent, while after the intervention, a difference of 21.3 percentage points was observed.

This conclusion is consistent with the literature, which highlights the potential of dynamic geometry environments to support learning. Küçük and Gün (2023), in a quasi-experimental study with experimental and control groups, observed better performance among students who used GeoGebra in geometry instruction. However, the authors found no differences between the groups. This result provides an important point of comparison for the present study: although both studies point to a favorable trend associated with GeoGebra, statistical evidence may vary depending on sample size, intervention duration, content covered, assessment instrument, and participant characteristics.

Consequently, the results of the present study should be interpreted not as evidence that GeoGebra necessarily produces superior effects in any context, but as evidence that, under the specific conditions of this intervention, students in the experimental group showed substantially greater improvement than that observed in the control group. This interpretation is methodologically more prudent and allows for a dialogue with the results of Küçük and Gün (2023), showing that the use of GeoGebra may be associated with improvements in performance, although the magnitude and significance of these improvements depend on the specific conditions of the intervention.

The results are also consistent with those of Chivai et al. (2024), who used a smartphone-adapted version of GeoGebra to teach spatial visualization in Descriptive Geometry. The authors found that both GeoGebra and Q3DM contributed to the development of spatial visualization skills in the experimental groups. The present analysis adds an important dimension to this evidence: the evolution of scores between the pretest and posttest. Thus, the results not only suggest an improvement in spatial abilities but also point to an improvement in academic performance in the topics covered.

The pedagogical explanation for this trend may be related to the characteristics of dynamic geometry environments. GeoGebra allows students to construct, modify, and observe geometric representations, providing them with a more dynamic relationship with the mathematical object. Instead of observing a static representation, students can follow transformations and establish relationships between different representations. This feature is particularly relevant for content that requires an understanding of spatial and geometric relationships.

In this regard, the results are consistent with the findings of Küçük and Gün (2023), who highlight GeoGebra's potential as dynamic geometry software and acknowledge its ability to improve performance, even though in their study this improvement did not reach statistical significance. The difference between the results of the

two studies reinforces the need to consider the pedagogical and methodological context in which the technology is used, and not merely the presence of the digital tool.

Learning Gains

To quantify students' individual progress and determine their learning gains, we used the gain coefficient c , proposed by Direnga et al. (2018). This coefficient allows us to assess the evolution of participants' performance between the pretest and posttest, taking into account their initial performance and the maximum possible level of learning. The c coefficient was calculated according to the equation proposed by Direnga et al. (2018):

$$c = \begin{cases} \frac{\text{post} - \text{pre}}{100\% - \text{pre}} & \text{se } \text{post} \geq \text{pre} \\ \frac{\text{post} - \text{pre}}{\text{pre}} & \text{se } \text{post} < \text{pre} \end{cases}$$

Individual learning gains were calculated for each student across the three pedagogical interventions: Study 1 and Study 2, which utilized Qubism 3D Modeling (Q3DM), and Study 3, conducted using GeoGebra. This analysis made it possible to evaluate individual performance trends, identify differences in the development of spatial skills, and examine potential gender-related variations. Analyzing the boys' individual gains allowed for the observation of each participant's progress between the pre-test and post-test, identifying improvements, stability, or declines in performance. This approach facilitated a deeper understanding of the interventions' effects by considering both general group trends and individual student variability. The results are presented in the Figures (see **Figures 1, 2, and 3**).

The data presented in **Figure 1** show individual learning gains ranging from 35% to 90% following the pedagogical intervention. These results indicate a positive trend in student performance, suggesting that the implemented strategy contributed to improved learning of the material covered. The variation in gains reveals individual differences linked to prior knowledge, spatial visualization abilities, and learning paces.

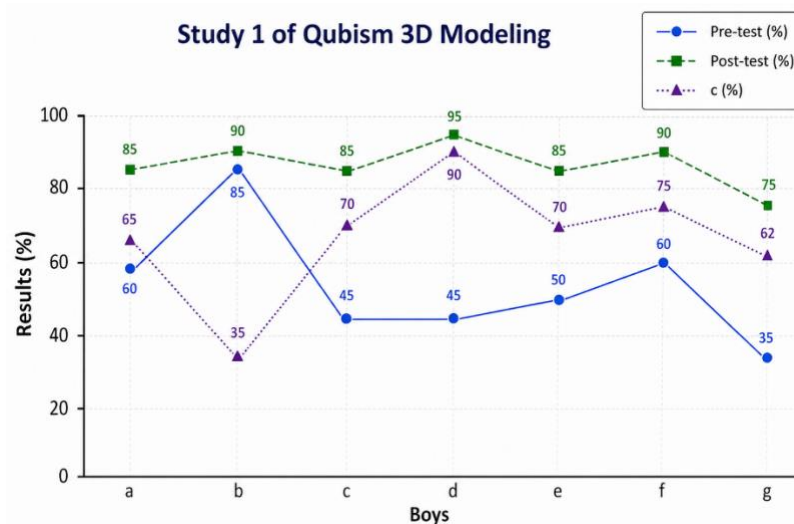


Figure 1. Boys' gains in Study 1 with Q3DM (Source: Authors)

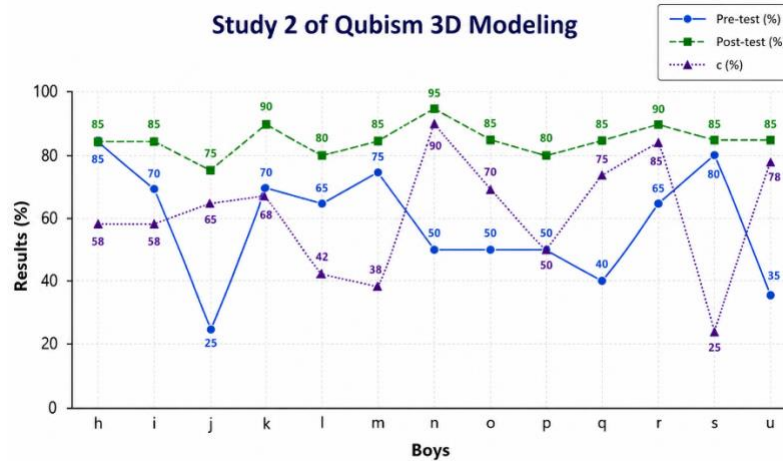


Figure 2. Boys' gains in Study 2 with Q3DM (Source: Authors)

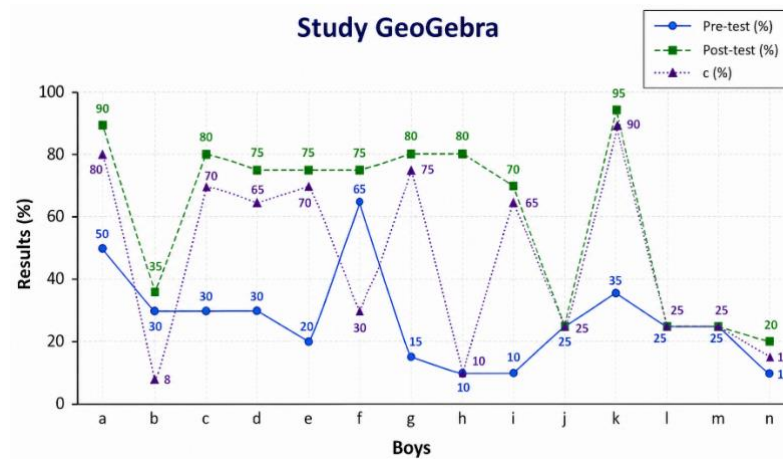


Figure 3. Boys' gains in the study using GeoGebra (Source: Authors)

The data presented in **Figure 2** show that the students' individual learning gains ranged from 25% to 90%. The positive progression between the pre-test and the post-test demonstrates improvements in content comprehension following the pedagogical intervention. The differences observed among the participants reveal distinct learning paces, possibly associated with prior knowledge, cognitive strategies, and the development of spatial visualization.

The data presented in **Figure 3** show individual learning gains ranging from 8% to 90%. The positive progression between the pre-test and post-test indicates that the pedagogical intervention contributed to improved understanding of the topics covered. The variation in results among participants reveals differing learning paces and cognitive characteristics. A combined analysis of **Figures 1, 2, and 3**, covering the three interventions (Studies 1 and 2 using Qubism 3D Modeling and Study 3 using GeoGebra) demonstrates a general trend of improved performance following the use of digital technologies. The results suggest that these applications fostered spatial visualization learning, contributing to the development of skills in interpreting, manipulating, and representing three-dimensional objects. Despite individual differences in the gains achieved, the prevalence of positive results highlights the contribution of interactive digital environments to the development of students' spatial skills, reinforcing the importance of integrating them into the teaching of Technical Drawing and Descriptive Geometry (see **Figures 4, 5, and 6**).

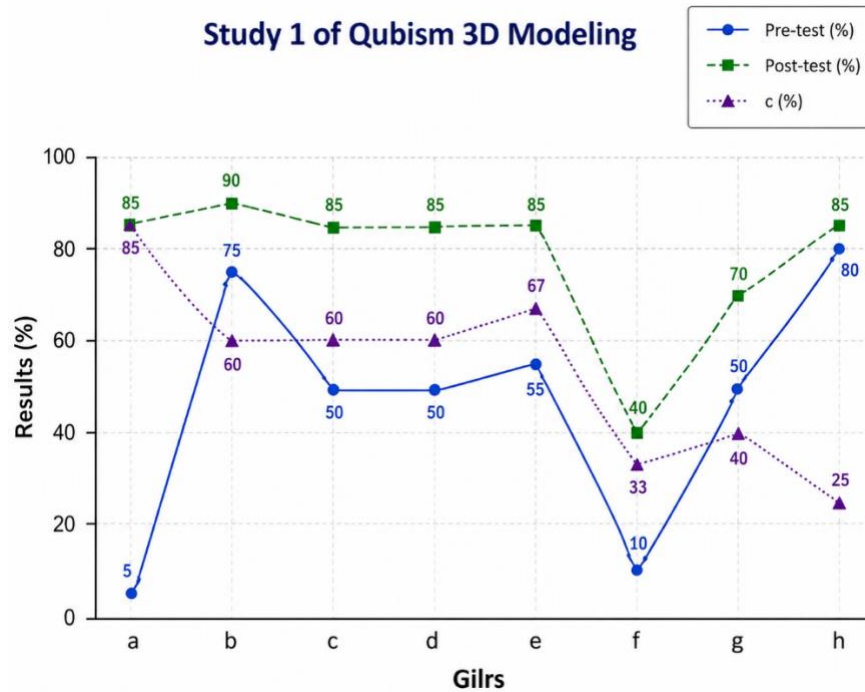


Figure 4. Girls' gains in Study 1 with Q3DM (Source: Authors)

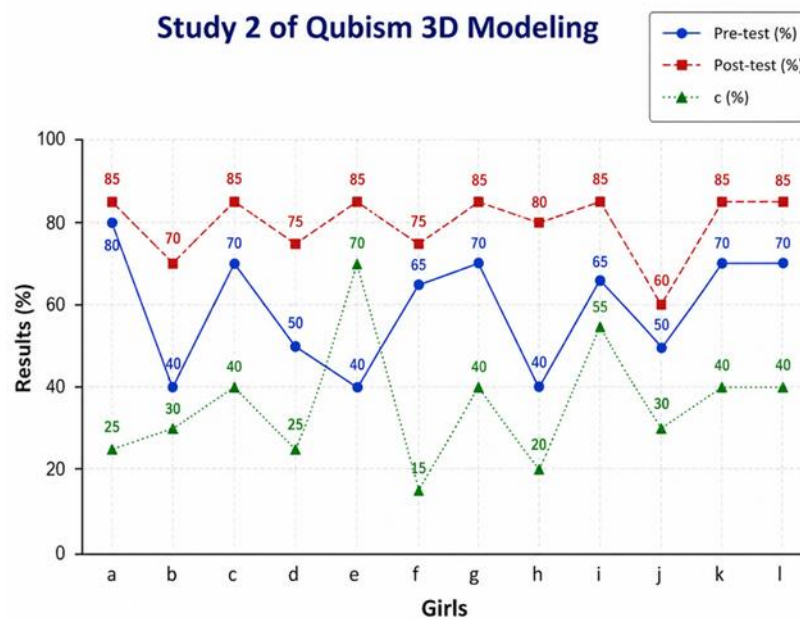


Figure 5. Girls' gains in Study 2 with Q3DM (Source: Authors)

The data presented in **Figure 4** show individual learning gains ranging from 25% to 85%, indicating a positive trend in performance between the pre-test and the post-test. These results suggest that the pedagogical intervention contributed to improved understanding of the content, although differences in participant progress were observed likely linked to prior knowledge, spatial visualization skills, and learning paces.

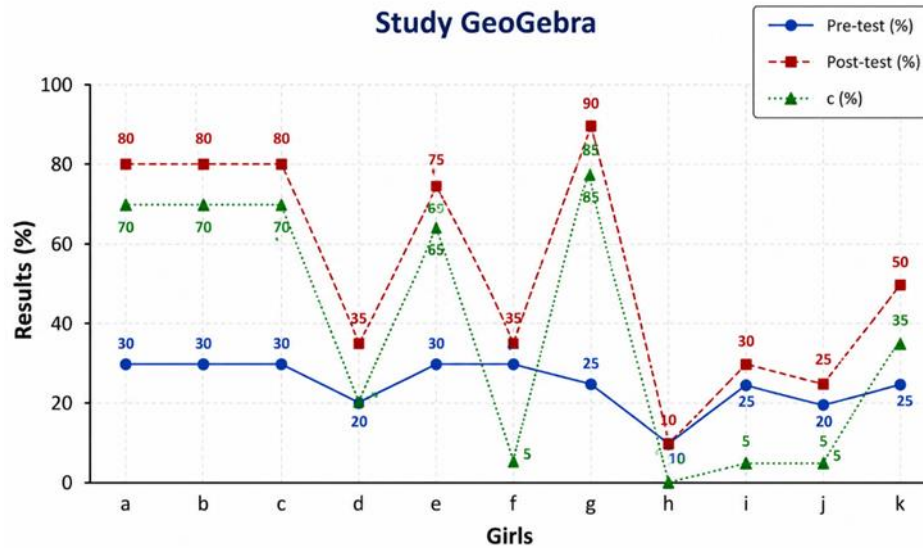


Figure 6. Girls' gains in the study using GeoGebra (Source: Authors)

Thus, the implemented strategy proved beneficial for the development of students' spatial skills, despite the variation in the magnitude of individual gains. The data presented in **Figure 5** show individual learning gains of more than 15% and less than 70%. These results indicate a positive evolution in student performance between the pre-test and post-test, suggesting that the pedagogical intervention contributed to improved learning of the material covered. The variation observed among participants demonstrates differing levels of progress, highlighting that students exhibited distinct paces in acquiring knowledge and developing spatial visualization skills.

The data presented in **Figure 6** show individual learning gains ranging from 0% to 85%, revealing a positive evolution in performance between the pre-test and the post-test. These results suggest that the pedagogical intervention contributed to the development of the assessed competencies, albeit with varying levels of progress among participants, differences possibly linked to prior knowledge, cognitive abilities, and individual learning paces. To complement the individual analysis, the collective learning gain was calculated using the normalized average gain “g”. According to Direnga et al. (2018), this measure allows for the assessment of a pedagogical intervention's effectiveness by determining the proportion of learning achieved relative to the potential gain. Thus, the normalized average gain enables a comprehensive analysis of the groups' progress by considering the difference between pre-test and post-test results, as represented by the following expression:

$$g = \frac{\text{absolute gain}}{\text{maximum possible gain}}$$

$$= \frac{(\text{post})_{\text{ave}} - (\text{pre})_{\text{ave}}}{100\% - (\text{pre})_{\text{ave}}}$$

This indicator allowed for a comparison of the mean results obtained in the students' pre-tests and post-tests, making it possible to analyze the evolution of participant performance following the pedagogical interventions. The analysis took into account 95% confidence intervals, enabling the estimation of result variability and the assessment of the consistency of differences observed between the assessment points and the groups analyzed (see **Figure 7**).

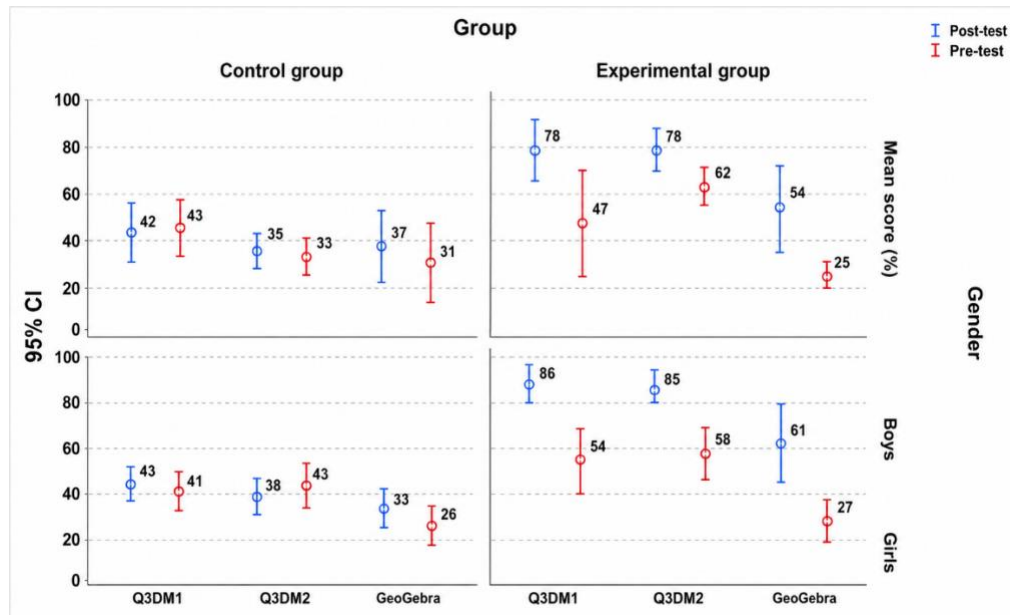


Figure 7. Comparison of pre-test, post-test, and normalized average learning gain for the cases using Qubism 3D Modeling and GeoGebra (Source: Authors)

Figure 7 highlights the performance differences between the experimental and control groups across both genders that used Qubism 3D Modeling and GeoGebra. The experimental groups achieved post-test results ranging from 54% to 86%, whereas the control groups recorded scores between 33% and 42%, revealing a more significant improvement in the groups that used digital technologies. These results suggest that exploring three-dimensional models and dynamic geometry environments fostered learning of the topics covered. These findings align with Silva and Pazuch (2024), who emphasize the contribution of Descriptive Geometry software to the development of spatial visualization and the understanding of geometric concepts, particularly when students interact with different representations and dynamically explore object properties.

Overall, the experimental groups outperformed the control groups, demonstrating the potential of digital technologies to mediate learning. Manipulating virtual objects, observing different perspectives, and linking three-dimensional and two-dimensional representations appear to have contributed to a more robust geometric understanding.

Regarding gender, boys showed higher average gains than girls, a difference that may be linked to factors such as prior experience, familiarity with digital technologies, and cognitive strategies. It was also observed that the greatest gains occurred in the Q3DM studies compared to GeoGebra, possibly due to the nature of the content. Orthographic projections facilitate the direct exploration of three-dimensional objects and their views, whereas cylinder sections require a higher level of geometric abstraction; thus, the specific characteristics of each tool may have influenced the results.

Pre-test and post-test results demonstrated a positive evolution in student performance across the three interventions conducted using Qubism 3D Modeling (Q3DM) Studies 1 and 2 and GeoGebra. Overall, the implemented strategies contributed to the development of spatial visualization skills and to the understanding of concepts related to orthographic projections and cross-sections of solids. Greater individual gains were observed in the studies using Q3DM. In Study 1, boys showed gains ranging from 35% to 90% and girls from 25% to 85%; in Study 2, the figures ranged from 25% to 90% for boys and from 15% to 70% for girls. In the

GeoGebra study, gains ranged from 10% to 90% for boys and from 0% to 80% for girls. The variation in results highlights differing learning paces, likely linked to prior knowledge, cognitive strategies, and initial levels of spatial visualization.

Comparisons between the experimental and control groups revealed differences following the interventions. Experimental groups achieved post-test averages ranging from 61% to 86%, whereas control groups showed values between 33% and 43%. These results suggest that Q3DM and GeoGebra fostered more favorable learning conditions by enabling the manipulation of 3D models, the exploration of perspectives, and the linking of spatial and planar representations. These results are consistent with Silva and Pazuch (2024), who highlight the contribution of digital technologies to the teaching of geometry, particularly through the dynamic exploration of representations and the manipulation of virtual objects. According to these authors, digital environments foster the understanding of abstract geometric concepts and the development of spatial visualization skills. Likewise, the findings corroborate Uribe-Flórez and Wilkins (2010), who demonstrate the potential of interactive digital environments for developing spatial skills and understanding the principles of descriptive geometry.

Overall, the results show that the experimental groups outperformed the control groups, highlighting the benefits of technology integration for both genders. It was also observed that the gains achieved with Q3DM were greater than those obtained with GeoGebra, possibly due to Q3DM's closer resemblance to the direct manipulation of three-dimensional objects and the specific characteristics of the content covered. Thus, the results reinforce the potential of digital technologies as complementary resources in the teaching of Descriptive Geometry, fostering more interactive learning environments and promoting the development of spatial visualization and geometric understanding (Chivai et al., 2024; Silva & Pazuch, 2024).

Results of the Pedagogical Intervention

A qualitative analysis of the pedagogical interventions revealed differences between the learning experiences of the experimental and control groups, particularly with regard to student participation, autonomy in completing tasks, and the development of spatial visualization. Overall, the results indicated that the combination of the teacher's pedagogical guidance and the use of interactive digital technologies facilitated the understanding of spatial geometry content that requires the integration of three-dimensional and two-dimensional representations. The intervention thus revealed that the development of spatial visualization skills does not depend exclusively on exposure to content, but also on the opportunities provided to students to observe, manipulate, experiment with, compare, and interpret different geometric representations. One of the most evident aspects during the interventions was the role played by the teacher as a mediator in the learning process. The use of technological resources, on its own, did not guarantee understanding of the content; the results showed that the teacher's intervention was essential for guiding the exploration of models, formulating questions, clarifying doubts, and establishing connections between the representations observed in the digital environment and the concepts covered in class. This finding is consistent with Libâneo (2013), who argues that the teacher plays an essential role in organizing instructional situations and creating conditions that enable students to actively construct knowledge. In this sense, technology served a complementary role to pedagogical action, expanding the possibilities for exploration and representation, but without replacing the teacher's guidance and instructional intent.

In the experimental group, students participated more actively in the proposed activities. The opportunity to manipulate three-dimensional objects, change perspectives, observe different positions, and analyze the transformations of solids sparked greater curiosity and engagement in completing the tasks. Students demonstrated a greater willingness to experiment with different strategies and to immediately observe the consequences of their actions on the geometric models. This dynamic helped shift students from a predominantly receptive role to more active participation in the learning process, fostering the gradual

construction of mental representations of spatial objects. In the case of Qubism 3D Modeling (Q3DM), the ability to build and manipulate three-dimensional models proved particularly relevant for teaching orthogonal projections. The three-dimensional representation allowed students to establish a more concrete relationship between the object and its projections, facilitating their understanding that different two-dimensional views can represent the same spatial object. Manipulating the model made it possible to observe the solid from different angles and understand the correspondence between its spatial characteristics and the projected representations. In this way, Q3DM helped make relationships more explicit that, through exclusively two-dimensional representations, might have remained abstract or difficult to understand.

This evidence is particularly relevant given the difficulties inherent in learning content that requires a high level of abstraction and spatial reasoning. As discussed by Gegenfurtner and Kollar (2024), certain learning tasks can become more challenging when students need to mentally construct relationships between different representations or understand phenomena that are not directly observable. In the present study, the use of interactive digital models appears to have partially reduced this difficulty, since students were able to observe and manipulate the objects before creating their graphical representations. Thus, the visual and interactive experience provided by Q3DM supported the formation and refinement of mental images of three-dimensional objects. Similarly, the use of GeoGebra in activities related to cross-sections of cylinders provided students with opportunities to dynamically explore the geometric relationships involved. The ability to modify elements, observe changes, and analyze different configurations allowed for a less static approach to the content. Instead of relying exclusively on figures previously drawn on the board or in the textbook, students were able to visually follow the transformations and relate them to the concepts they were studying. This feature proved important for understanding situations in which the position of the cutting plane and the configuration of the solid directly influence the representation of the resulting cross-section.

The results observed are consistent with those of Küçük and Gün (2023), who highlight the potential of interactive digital tools in geometry instruction, particularly because they enable the exploration of different perspectives, properties, and spatial relationships. The interactivity provided by digital environments appears to foster learning based on exploration and experimentation, allowing students to formulate hypotheses, observe results, and revise their interpretations. In this study, this capability was particularly important for content where understanding is not limited to identifying properties but also requires the ability to establish relationships between different positions, views, and representations. In the control group, although progress in learning was also observed, the process exhibited distinct characteristics. Students relied to a greater extent on the teacher's explanations and direct guidance, as well as on the traditional resources used in class. The representation of objects remained predominantly static, limiting the opportunities to observe different perspectives and to independently test changes in the models. Consequently, tasks that required switching between three-dimensional and two-dimensional representations proved more complex, especially when students needed to mentally visualize transformations that were not directly represented.

It is important to note, however, that the lower level of interactivity observed in the control group does not imply a lack of learning. The results show that traditional strategies, when accompanied by the teacher's explanations, examples, and guidance, continue to contribute to content learning. The difference lies primarily in the opportunities for exploration offered to students. While in the control group the construction of spatial representations occurred predominantly through the observation of figures and the teacher's explanation, in the experimental group students had the additional opportunity to interact directly with the models. Technology, therefore, should not be viewed as a substitute for traditional methodologies, but rather as a resource capable of expanding the possibilities for representing and exploring content. In this context, digital technologies can be understood as cognitive mediators, in that they help bridge the gap between abstract concepts and manipulable visual representations. The ability to view, rotate, zoom in on, transform, and compare models facilitates the externalization of spatial processes that, under exclusively traditional conditions, must be carried out mentally by the student. This mediating function is particularly important in

the teaching of spatial geometry, where learning depends on the ability to coordinate different systems of representation. The results suggest that, by making certain spatial relationships visible, digital environments can reduce the cognitive load associated with the initial construction of these representations and allow students to focus more attention on interpreting geometric concepts. Another significant outcome was the development of students' autonomy. During activities with Q3DM and GeoGebra, it was observed that students gradually began to explore the models without constantly relying on the teacher's intervention. The ability to experiment with different configurations and receive immediate visual feedback created the conditions for more self-regulated learning. Students could test a particular representation, verify whether it matched the expected result, and, if necessary, modify their strategy. This process fostered not only the acquisition of geometric knowledge but also the development of investigative and problem-solving skills.

A comparison between the groups therefore suggests that the main contribution of the technologies used lay not only in the more attractive presentation of the content, but also in transforming the ways in which students could interact with the learning objects. In the experimental group, interaction with the models bridged the gap between the concrete, the visual, and the abstract, thereby facilitating an understanding of spatial relationships. In the control group, learning occurred primarily through observation, explanation, and static representation, which required students to rely more heavily on their abilities for abstraction and spatial imagination. This difference helps explain the more significant improvements observed in the experimental group. The results also suggest that the effectiveness of digital technologies is related to how they are integrated pedagogically. Simply introducing a digital app into the classroom does not, in and of itself, guarantee better results. Teachers must set clear objectives, select appropriate tasks, guide students in exploring resources, and encourage moments of reflection on what is being observed. Technology yields greater pedagogical value when it is integrated with teaching strategies that guide students from exploration to conceptualization. Thus, digital interaction should be accompanied by questioning, discussion, explanation, and the systematization of knowledge.

This perspective is also supported by Küçük Avcı et al. (2019), whose findings highlight the contribution of interactive digital environments to the learning of geometry and the development of spatial skills. In the present study, this contribution was evident primarily in the ability to provide learning experiences that were more dynamic, visual, and centered on student action. Exploring digital models allowed students to establish relationships between different representations, develop their own strategies, and visually verify the results of their actions.

In summary, the qualitative results of the pedagogical intervention indicate that the integration of Q3DM and GeoGebra, when accompanied by appropriate teacher guidance, contributed to the creation of more interactive, participatory, and student-centered learning environments. These technologies facilitated the exploration, manipulation, and dynamic visualization of geometric objects, supporting the understanding of the relationships between three-dimensional and two-dimensional representations and contributing to the development of spatial visualization. Although the control group also showed progress, the experience of the experimental group provided greater opportunities for independent exploration and the construction of mental representations. Thus, the results reinforce the idea that the pedagogical integration of digital technologies can be an effective strategy for addressing challenges associated with the teaching and learning of spatial geometry. However, their potential depends on the integration of technology, content, and pedagogy. The teacher continues to play a central role in guiding experiences, interpreting representations, and reinforcing concepts. Thus, rather than replacing existing teaching practices, Q3DM and GeoGebra expand the available methodological repertoire, providing new ways to visualize, explore, and understand spatial objects and relationships.

CONCLUSION

The results demonstrate that the use of Q3DM and GeoGebra contributed to improved learning regarding orthographic projections and solid sections, fostering the development of spatial visualization skills and enhancing student performance. Experimental groups achieved superior results compared to control groups, highlighting the potential of digital technologies in understanding abstract geometric concepts. The research also revealed higher levels of participation, motivation, autonomy, and engagement among students who used these technological resources. Furthermore, the findings reinforce the teacher's role as a learning mediator, with technologies serving as supportive tools that enhance knowledge construction. Thus, it is concluded that integrating three-dimensional technologies into Technical Drawing instruction constitutes an effective pedagogical strategy for promoting more meaningful learning and developing spatial skills. Future recommendations include conducting studies in diverse educational settings and exploring emerging technologies such as augmented reality and virtual reality within the teaching of Geometry and Technical Drawing.

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