Ioana-Roxana VIZITIU-BACIU, Liviu PRUNĂ, Andrei SLONOVSCHI, Alexandru-Ionuț IRIMIA, Sebastian George MAXINEASA

INTEGRATING AI-BASED VISUALIZATION WITH TRADITIONAL DESCRIPTIVE GEOMETRY INSTRUCTION

Abstract: *Descriptive geometry is essential in engineering education, supporting spatial reasoning and problem-solving through projections. Many students, however, find it difficult to interpret orthographic views and reconstruct 3D objects from 2D drawings. Advances in artificial intelligence have introduced visualization tools that generate interactive models and provide real-time feedback during modeling. This paper examines the role of AI-assisted visualization in teaching descriptive geometry and its educational impact. It analyzes how these tools can enhance spatial understanding while preserving core skills such as manual construction and geometric reasoning. The results indicate that integrating AI-based visualization with traditional methods improves conceptual understanding, reduces interpretation errors, and increases student engagement.*

Keywords: *descriptive geometry, artificial intelligence, spatial visualisation, engineering graphics, engineering education.*

1. INTRODUCTION

Descriptive geometry has long been a key part of engineering education. Since Gaspard Monge formalised projection methods, this discipline has offered a way to represent three-dimensional objects using flat projections. In engineering graphics education, descriptive geometry helps students examine spatial relationships and communicate complex technical ideas through drawings [1], [2], [3].

Technical drawings and projection systems serve as the common language for engineering communication (Figure 1). Engineers use orthographic projections, sectional views, and auxiliary drawings to clearly interpret design solutions and accurately show spatial arrangements. Thus, mastering these graphical standards is crucial for professionals in fields like mechanical engineering, civil engineering, architecture, and industrial design [1], [4].

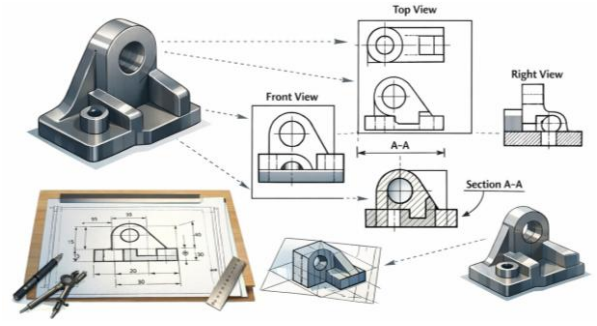


Figure 1 Orthographic projection and technical drawing serve as the common language for communication in engineering.

Despite its importance, descriptive geometry is frequently perceived as a difficult subject by students. One of the main reasons lies in the cognitive effort required to mentally transform two-dimensional representations into accurate three-dimensional mental models. Students often struggle with identifying hidden features, analysing surface intersections, or interpreting projection transformations.

Traditional teaching approaches rely mainly on manual constructions, sketching exercises, and teacher-led demonstrations. While these methods remain essential for developing geometric discipline and analytical thinking, they may not always provide sufficient visualisation support for learners with lower spatial abilities [2].

Recent advances in artificial intelligence technologies have introduced new opportunities for enhancing engineering graphics education. AI-based visualisation systems can generate geometric representations automatically, convert symbolic descriptions into spatial models, and provide real-time feedback during modelling activities [5], [6].

From the perspective of teaching practice, the emergence of such technologies raises an important pedagogical question: *how can intelligent visualisation tools support descriptive geometry instruction while preserving the fundamental role of geometric reasoning?* This paper explores this question by analysing recent research and discussing possible pedagogical integration strategies.

2. LITERATURE REVIEW

2.1 Spatial Visualisation in Engineering Education

Spatial visualisation is widely considered one of the most important factors in how well students do in engineering graphics courses. Research by Sorby shows that being able to mentally rotate objects and understand projection systems is crucial for reading technical drawings and solving engineering problems [2], [7].

In practice, students with weaker spatial skills often find it harder to reconstruct three-dimensional objects from orthographic views. Things like recognising hidden edges or understanding sectional planes can be especially challenging (Figure 2). Studies also suggest that these difficulties can affect students' confidence and sometimes slow their progress in project-based subjects [8].

Several researchers have therefore investigated methods for improving spatial visualisation skills through targeted educational interventions. Visualisation exercises, three-dimensional modelling environments, and interactive graphical systems have been shown to enhance students' ability to interpret complex geometric relationships [8].

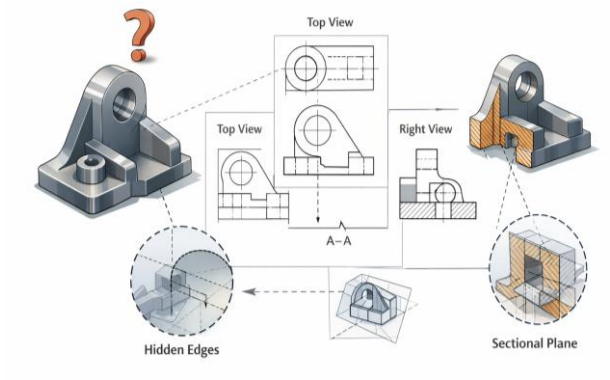


Figure 2 Challenges in interpreting hidden edges and sectional planes in orthographic projection.

Nevertheless, spatial abilities vary considerably among students entering engineering programs. This variability represents an important pedagogical challenge for educators, who must design learning environments that accommodate different levels of spatial reasoning.

2.2 Digital Visualisation Technologies in Engineering Graphics

The introduction of computer-aided design systems represented a significant development in engineering graphics education. CAD environments enable students to generate complex geometric models and explore spatial relationships with a high degree of precision and flexibility [3], [4].

However, traditional CAD systems often require extensive software training and rely heavily on command-based interaction. For novice students, learning to operate the interface may impose an additional cognitive load that can divert attention from the conceptual understanding of geometric principles.

Consequently, recent educational research has examined visualisation platforms specifically designed to reduce cognitive load while supporting conceptual learning. Interactive modelling environments allow learners to manipulate geometric objects dynamically and observe spatial transformations in real time [7].

Such systems facilitate the connection between abstract geometric concepts and perceptual representations, thereby supporting the development of spatial reasoning abilities.

2.3 Artificial Intelligence in Engineering Education

Artificial intelligence technologies have recently emerged as promising tools for supporting learning processes. AI-based systems can deliver adaptive feedback, generate visual explanations, and guide students throughout problem-solving activities.

In engineering education, AI-assisted visualisation tools can automatically generate geometric models and support students in interpreting complex projections. These systems can highlight hidden geometric relationships, simulate spatial transformations, and provide step-by-step visual explanations during modelling tasks [6], [9].

Such technologies have the potential to reduce the cognitive barriers associated with projection-based learning. Through immediate visual feedback, AI-assisted systems enable learners to explore spatial structures more intuitively and develop a deeper understanding of geometric relationships.

Nevertheless, researchers also emphasise the importance of integrating these tools carefully into educational contexts to avoid excessive reliance on automated modelling processes.

3. DISCUSSION: PEDAGOGICAL IMPLICATIONS AND INSTRUCTIONAL INTEGRATION

3.1 Cognitive Challenges in Descriptive Geometry Learning

From the perspective of classroom practice, one of the most persistent challenges in descriptive geometry courses concerns the cognitive complexity associated with projection-based reasoning. Students are required to interpret multiple orthographic views simultaneously while maintaining a coherent understanding of the spatial relationships between geometric elements (Figure 3).



Figure 3 Interpreting multiple orthographic views in spatial reasoning tasks.

Unlike many other engineering subjects, descriptive geometry requires learners to continuously translate between two distinct representational systems: the planar projection and the spatial object it represents [10].

When solving problems involving surface intersections, auxiliary projections, or transformations between projection planes, students must coordinate several cognitive processes simultaneously. These include visualising spatial configurations, interpreting projection rules, and carrying out the procedural steps of construction. The need to manage these processes concurrently can place significant demands on working memory.

In teaching practice, such difficulties often become apparent during exercises involving complex spatial configurations. Students may accurately reproduce procedural steps while still struggling to grasp the geometric meaning of the constructions. In these cases,

learning may become primarily procedural rather than conceptual, with students focusing more on following instructions than on analysing spatial relationships.

Another frequently observed aspect in introductory descriptive geometry courses is the variation in students' spatial visualisation abilities. Some students can mentally reconstruct three-dimensional objects from projections with relative ease, whereas others require substantial visual support to achieve a comparable level of understanding. Consequently, educators often work with heterogeneous groups in which the pace of conceptual development varies considerably.

These cognitive demands underscore the importance of instructional approaches that offer additional visualisation support while preserving the analytical reasoning processes characteristic of descriptive geometry.

3.2 Pedagogical Role of AI-Assisted Visualisation

AI-assisted visualisation technologies introduce new opportunities for supporting learning in projection-based disciplines. In contrast to conventional modelling environments that rely on extensive manual interaction, AI-driven systems can automatically generate geometric models, interpret symbolic descriptions, and dynamically illustrate projection transformations.

From a pedagogical perspective, the primary value of these technologies lies in their function as visual cognitive support tools. By translating abstract geometric constructions into dynamic spatial representations, AI-assisted environments help students develop clearer mental models of geometric structures [10], [11].

In traditional descriptive geometry instruction, students are often required to mentally simulate how successive projection operations affect a spatial object. This process can be particularly demanding for beginners who have not yet developed strong spatial reasoning skills. AI-based visualisation platforms can support this process by making geometric transformations both visible and interactive.

For instance, when analysing the intersection of two surfaces, students typically construct the intersection curve through a sequence of projection steps. In an AI-assisted visualisation environment, the resulting spatial configuration can be displayed simultaneously with the projection procedure. This dual representation enables students to better understand the relationship between the geometric construction and the spatial form it represents.

Moreover, intelligent visualisation systems can provide immediate feedback when modelling errors occur. By identifying incorrect geometric relationships or inconsistencies in projection steps, these tools allow learners to detect mistakes more efficiently and refine their reasoning processes [12].

From an instructional standpoint, AI-assisted visualisation should therefore be understood as supportive rather than substitutive. The aim is not to automate geometric reasoning, but to clarify the spatial logic underlying projection-based constructions.

3.3 A Pedagogical Integration Model for AI-Supported Geometry Instruction

Based on both existing research and classroom experience in descriptive geometry, a structured pedagogical integration model can be proposed for the effective use of AI-assisted visualisation tools. The model emphasises the complementary relationship between traditional geometric reasoning and intelligent visualisation technologies.

The proposed framework consists of three instructional stages corresponding to different phases of the learning process.

Stage 1 – Conceptual Visualisation

The first stage focuses on developing an initial conceptual understanding of the geometric problem. At this stage, the teacher uses AI-assisted visualisation tools to illustrate spatial relationships and projection transformations. Dynamic representations of geometric objects allow students to observe how projection operations affect the spatial configuration of the model (Figure 4).

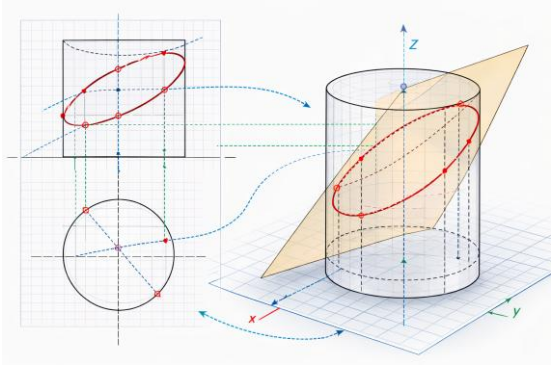


Figure 4 Stage 1: Conceptual visualisation stage in AI-supported descriptive geometry instruction.

The purpose of this stage is to reduce the initial cognitive barrier associated with interpreting complex spatial structures. Through visual observation of geometric transformations, students can develop a more intuitive understanding of the relationships between projections and spatial forms.

Stage 2 – Guided Analytical Construction

In the second stage, students carry out geometric constructions manually using classical descriptive geometry methods. This phase emphasises analytical reasoning, projection logic, and procedural accuracy (Figure 5).

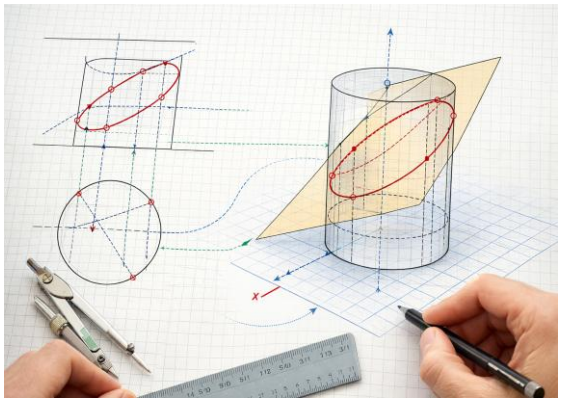


Figure 5 Stage 2: Guided analytical construction stage in AI-supported descriptive geometry instruction.

Manual construction remains essential for developing the methodological discipline characteristic of descriptive geometry. By following step-by-step projection procedures, students gain a clearer understanding of how geometric relationships are derived and how spatial configurations can be analysed systematically.

During this stage, educators may also encourage students to compare their manual constructions with the spatial configurations previously observed in the visualisation phase. Such comparisons help reinforce the connection between procedural steps and spatial meaning.

Stage 3 – Reflective Visualisation and Verification

The third stage involves the use of AI-assisted visualisation tools to verify and further analyse the results of manual constructions. Students can compare their geometric solutions with dynamically generated spatial models and examine how individual projection steps correspond to the resulting spatial configuration (Figure 6).

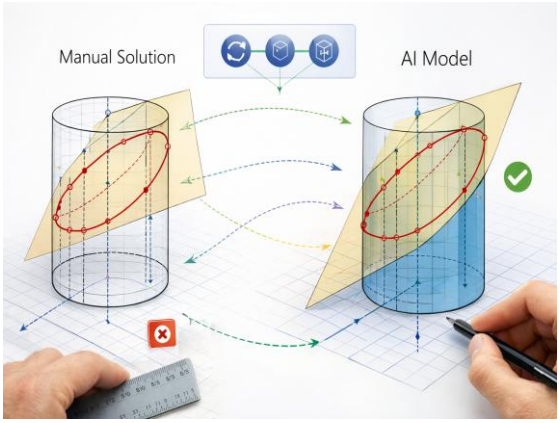


Figure 6 Stage 3: Guided analytical construction stage in AI-supported descriptive geometry instruction.

This stage supports reflective learning by enabling students to evaluate their reasoning processes and identify potential errors in their constructions. In this context, the visualisation environment functions as a tool for conceptual validation rather than a substitute for analytical work.

Through this three-stage instructional sequence, AI-assisted visualisation technologies operate as complementary educational resources that enhance conceptual understanding while preserving the analytical foundations of descriptive geometry.

3.4 Pedagogical Value of Hybrid Visualisation Learning

The proposed model combines the strengths of traditional descriptive geometry instruction with the advantages of contemporary visualisation technologies. From the educational perspective, such integration enables the learning process to address both conceptual understanding and analytical reasoning simultaneously.

Manual construction remains fundamental for developing precision, logical thinking, and a disciplined approach to geometric problem solving. At the same time, AI-assisted visualization tools offer additional perceptual support that can facilitate the interpretation of spatial relationships.

Several pedagogical benefits emerge from this integrated approach. First, visualisation tools can help reduce the cognitive load associated with complex projection tasks, particularly in the early stages of learning. Second, dynamic representations enable students to engage more actively with geometric structures, encouraging an exploratory rather than purely procedural learning process.

Another important advantage lies in the support provided to students with lower initial spatial visualisation abilities. By offering visual scaffolding during complex modelling tasks, AI-assisted systems can reduce frustration and strengthen learner confidence.

Finally, interactive visualisation environments often increase student engagement in geometry instruction. When learners can observe geometric transformations dynamically and explore spatial configurations independently, they are more likely to develop sustained interest in the subject.

In this context, AI-assisted visualisation technologies may be understood as cognitive amplifiers that extend the explanatory capacity of descriptive geometry instruction. When carefully integrated into teaching practice, they can enhance the learning experience while preserving the intellectual discipline that characterises geometric reasoning.

3.5. Limitations and pedagogical risks of AI-assisted visualisation

While AI-assisted visualisation tools offer considerable potential for improving descriptive geometry instruction, their integration requires careful attention to inherent limitations and pedagogical risks. A central concern relates to the possibility of fostering excessive student dependence on automated systems. When learners rely extensively on AI-generated models for spatial interpretation, they may insufficiently develop essential mental rotation abilities and independent projection reasoning—core competencies of descriptive geometry education. Such dependence risks shifting learning from active analytical problem-solving toward more passive model exploration, thereby weakening the formative objectives of the discipline.

Technical reliability represents an additional challenge. Contemporary AI visualisation systems may occasionally produce geometrically inaccurate representations, misinterpret sketch-based inputs, or apply projection conventions inconsistently with established engineering graphics standards. Novice learners, who are still developing their conceptual frameworks, may lack the expertise needed to critically evaluate such outputs and may therefore internalise incorrect spatial relationships. Moreover, the “black box” character of many AI models can obscure the underlying computational logic, limiting students’ ability to trace projection reasoning processes.

Assessment alignment also constitutes a relevant concern. Learning environments enriched with continuous visual support may not adequately prepare students for assessment contexts that require independent

mental visualisation and manual construction. This discrepancy may lead to the development of technically competent users of software tools rather than geometrically literate engineers capable of reasoning without continuous technological assistance.

Finally, institutional readiness varies considerably across educational contexts. Limited access to appropriate hardware, software licenses, or academic staff training may contribute to disparities in learning opportunities. Without systematic professional development, AI-assisted visualisation risks remaining an underutilised technological resource rather than an effectively integrated instructional approach. These considerations highlight the importance of carefully scaffolded implementation that preserves the analytical rigour of descriptive geometry while employing intelligent visualisation as a form of cognitive support.

3.6 Applied Example: Determining the Intersection Between an Oblique Plane and a Right Prism

To illustrate the three-stage pedagogical model, consider a representative descriptive geometry problem: determining the intersection curve between an oblique plane and a right prism, represented in Figure 7 and Figure 8.

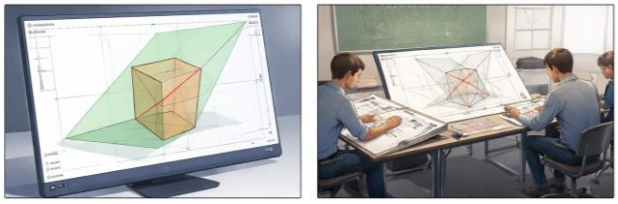


Figure 7 The first two stages of the pedagogical model for determining the intersection between an oblique plane and a right prism.

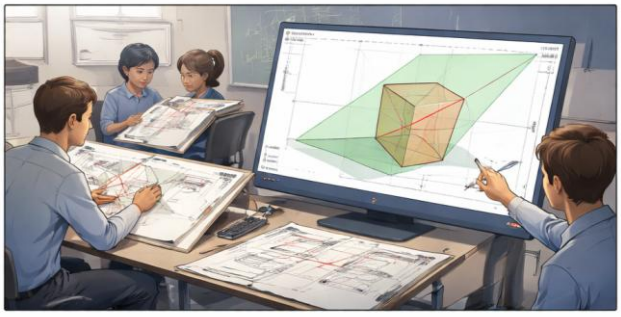


Figure 8 The third stage of the pedagogical model for determining the intersection between an oblique plane and a right prism.

Stage 1 – Conceptual Visualisation: The teacher uses an AI-assisted visualisation platform to present the prism and plane within a dynamic three-dimensional environment. Students observe how the oblique plane intersects the prism, producing a visible polygonal curve. Through interactive rotation, they examine how the intersection projects onto the principal planes, thereby establishing intuitive spatial relationships before formal construction.

Stage 2 – Guided Analytical Construction: Students then perform the construction manually using classical descriptive geometry techniques. This includes projecting the trace of the plane onto the horizontal and vertical planes, identifying intersection points along the prism edges, and systematically constructing the generators. During this stage, the teacher monitors procedural accuracy while limiting software use to maintain emphasis on projection logic and analytical discipline.

Stage 3 – Reflective Visualisation and Verification: Finally, students compare their manual solutions with a dynamically generated spatial model within the AI environment. Common errors—such as incorrect generator orientation, omitted intersection points, or inaccurate hidden-line representation—become readily apparent. Subsequent discussion supports the analysis of these discrepancies and reinforces the relationship between procedural operations and spatial.

This concrete scenario demonstrates how AI visualisation functions as scaffolded cognitive support across instructional phases while preserving manual construction's analytical value.

4. FUTURE DIRECTIONS

The integration of artificial intelligence into descriptive geometry education remains an emerging research field with several promising directions for both technological development and pedagogical innovation. As intelligent visualisation tools become more accessible, it is important to investigate how these technologies influence the learning process and the development of spatial reasoning abilities in engineering students.

First, further empirical studies are needed to evaluate the long-term educational impact of AI-assisted visualisation environments. While preliminary results indicate improvements in spatial comprehension and conceptual understanding, additional research should analyse whether these benefits persist over time and contribute to the sustained development of spatial reasoning skills throughout engineering curricula.

Second, future research should focus on developing adaptive visualisation systems that adjust the complexity of geometric representations based on students' spatial abilities. Intelligent educational platforms could analyse learners' performance and provide personalised levels of visual guidance, gradually reducing assistance as students develop stronger spatial reasoning capabilities.

Another promising research direction involves the integration of AI-based visualisation with immersive technologies such as augmented reality (AR) and virtual reality (VR). These environments may enable students to interact directly with geometric structures in fully three-dimensional spaces, improving their ability to perceive spatial relationships and explore complex geometric transformations more intuitively.

Finally, interdisciplinary collaboration between educators, computer scientists, and cognitive researchers will be essential for designing visualisation technologies that align with sound pedagogical principles. Such collaboration can ensure that technological innovation in

AI-assisted geometry learning supports meaningful educational outcomes while maintaining the intellectual rigour that characterises descriptive geometry instruction.

5. CONCLUSIONS

Descriptive geometry continues to play a crucial role in engineering education by developing spatial reasoning and projection-based problem-solving abilities. However, traditional instructional approaches may not always provide sufficient visualisation support for students with diverse spatial abilities.

Artificial intelligence technologies introduce promising opportunities for enhancing descriptive geometry learning through interactive visualisation, automated modelling, and adaptive feedback mechanisms.

From a pedagogical perspective, the most effective approach is not to replace traditional descriptive geometry instruction but to integrate intelligent visualisation tools into existing teaching practices.

A balanced combination of classical geometric reasoning and AI-assisted visualisation environments may therefore represent an important step toward modernising engineering graphics education.

The proposed three-stage pedagogical integration model provides engineering graphics educators with a practical framework for integrating AI-assisted visualisation while preserving the analytical foundations of descriptive geometry. By sequencing conceptual visualisation, guided manual construction, and reflective verification, this approach accommodates diverse spatial abilities while maintaining methodological rigour. Beyond descriptive geometry, the hybrid model also shows potential for adaptation across related graphics disciplines—such as introductory CAD instruction, technical drawing courses, and surveying visualisation—where projection-related challenges persist.

Successful implementation requires intentional instructional design: clearly defining AI's supportive role, maintaining assessment alignment with independent geometric competency, and investing in faculty development. When calibrated thoughtfully, AI-enhanced visualisation transforms from technological novelty into a cognitive amplifier, modernising engineering graphics education while honouring its geometric heritage.

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Authors:

Senior Lecturer Eng., Ph.D. Ioana-Roxana VIZITIU-BACIU ”Gheorghe Asachi” Technical University of Iași, Faculty of Civil Engineering and Building Services, Department of Engineering Graphics, Email: ioana-roxana.vizitiu-baciu@academic.tuiasi.ro

Associate Professor Eng., Ph.D. Liviu PRUNĂ, ”Gheorghe Asachi” Technical University of Iași, Faculty of Civil Engineering and Building Services, Department of Engineering Graphics, Email: liviu.pruna@academic.tuiasi.ro

Senior Lecturer Eng., Ph.D. Andrei SLONOVSCHI ”Gheorghe Asachi” Technical University of Iași, Faculty of Civil Engineering and Building Services, Department of Engineering Graphics, Email: andrei.slonovschi@academic.tuiasi.ro

Teaching Assistant Ph.D. eng. Alexandru-Ionuț IRIMIA, "Gheorghe Asachi" Technical University of Iași, Department of Graphic Communication, Email: alexandru-ionut.irimia@academic.tuiasi.ro

Senior Lecturer Eng., Ph.D. Sebastian George MAXINEASA,”Gheorghe Asachi” Technical University of Iași, Faculty of Civil Engineering and Building Services, Department of Civil and Industrial Engineering Email: sebastian-george.maxineasa@academic.tuiasi.ro