The Integration of Generative AI into a 4-Step Model for Teaching Descriptive Geometry in Higher Education

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Abstract.
This study examines the integration of generative artificial intelligence into higher education, specifically in descriptive geometry education with special attention on the development of spatial reasoning skills. The research presents an innovative four-step pedagogical model based on diagnostic assessment, adaptive curriculum design, collaborative learning, and continuous curriculum development. The model was tested among first-year engineering students at the University of Miskolc. The study suggests that the analysis of errors in diagrams generated by generative AI, combined with collaborative group work, significantly improved students' performance by the end of the semester. The results indicate that generative artificial intelligence tools can effectively support visualization, the identification of geometric errors, and the development of critical thinking skills. Students' performance showed considerable improvement because of these targeted interventions. Based on these findings, it can be concluded that generative artificial intelligence may play an important role in the methodological renewal of future engineering education.

Keywords: descriptive geometry, 4-step model, generative AI.

1 Introduction

The emergence of generative artificial intelligence has significantly reshaped the landscape of both public and higher education since the end of 2022, fundamentally transforming teaching, learning, and evaluation practices. International research highlights that GenAI tools, such as ChatGPT, not only provide administrative support but also create new opportunities and foster creativity, critical thinking, and autonomous learning [16]. The literature confirms that these technologies force a fundamental pedagogical reform in higher education, given their capability to summarize and generate content across multiple outcomes, including text, image, audio, and video results [4],[8],[12].

Descriptive geometry is considered a foundational subject in university-level engineering education. The aim of this study is to examine the role of generative artificial intelligence in university-level descriptive geometry education. The study also

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investigates the skills that these technologies may help develop and the ways in which they can support both instructors and students [19].

The paper presents the background to the pedagogical integration of generative AI, analyzes its potential for supporting visualization and problem-solving, and explores issues related to its methodological integration into education.

Several studies have been conducted in Hungary, which have shown that artificial intelligence is not only a technological advancement but also a significant pedagogical challenge. It raises questions about how it affects the attitudes, readiness, and digital competencies of both educators and learners [5].

Numerous studies have been conducted on how higher education faculty members view the role of AI, whether they use it in their daily teaching, and, if so, how they have integrated it into their teaching [7],[11],[18].

2 Artificial Intelligence in Education

In September 2020, the European Parliament established the Special Committee on Artificial Intelligence in a Digital Age (AIDA) to examine the impact of artificial intelligence. Although the committee produced eleven working papers covering various sectors [2], education was notably absent from these documents.

Education is often not considered a directly productive economic sector and therefore tends to receive less policy attention. This may partly explain why it was not included among the committee's focus areas. Nevertheless, the growing influence of artificial intelligence has made its integration into education increasingly unavoidable. The application of artificial intelligence in education has been documented since the 1970s [6],[13]. The role of artificial intelligence in education has been discussed since the early 1990s, and the International Artificial Intelligence in Education Society (IAIED), an organisation dedicated to research in this field, has been active since 1997 [10]. Over recent years, its role has evolved along several complementary directions.

2.1 The rise of generative artificial intelligence in education

Baker, Smith, and Anissa (2019) distinguish three main levels of AI application that reflect the key stakeholders within the educational system [4]. From the learner's perspective, AI supports learning processes and expands opportunities for self-assessment, thereby facilitating individualized learning pathways. From the teacher's perspective, AI supports teaching practices and improves the efficiency of instructional work. At the institutional level, AI contributes to the operation, management, and governance of educational organizations.

Other studies identify four major areas of AI application in education [12]. The first involves the automation of repetitive and administrative tasks, thereby reducing teachers' workload and allowing more time for instructional activities. The second concerns the continuous monitoring of learning progress, which supports the design of personalized development programs. The third area is the personalization of learning, enabling educational experiences that better address individual learner needs. Finally, AI may

enhance accessibility by supporting the development of learning environments that are more inclusive and accessible to a broader range of learners.

Yufeia et al. (2020) propose a more detailed classification of artificial intelligence applications in education, identifying at least ten distinct areas of use [20]. These include automated assessment systems, spaced repetition reminders for learning, support for instructor feedback, virtual tutoring systems, personalized and adaptive learning environments, the integration of augmented and virtual reality, content generation aligned with learners' knowledge levels, intelligent university systems, and distance learning solutions.

In several articles, AI-based educational tools are also categorized by their functional roles, including recommendation systems, predictive models, optimization methods, recognition technologies, and integrated AI systems. Among these, for example, recommendation systems can support both students and teachers. They can suggest personalized learning content or learning paths for students based on their individual characteristics and personal preferences. For educators, they can assist in preparing lesson plans, lesson outlines, assignments, or homework. By analyzing learning data, predictive systems identify students at risk of academic difficulties or dropping out. This enables targeted and timely intervention, particularly in online learning environments where large datasets are available [1],[14]. Furthermore, institutional-level data analysis and visualization can provide important support for educational decision-making processes [9].

Optimization systems play a central role in the personalization of education, as they enable learning pathways to be adapted to individual needs and knowledge levels. This includes the dynamic adjustment of learning materials, AI-based instructional support, and revision scheduling [20]. These approaches can be especially beneficial for students with special educational needs [8].

Recognition systems include educational chatbots and automated assessment tools, which are capable, using natural language processing, of interpreting student questions and evaluating detailed responses [12],[13]. However, the literature also notes that such systems may be susceptible to manipulation or circumvention in certain contexts [8].
Finally, complex systems refer to integrated AI solutions that support the everyday activities of both students and teachers. For learners, these systems may function as personal digital assistants, while for educators, they can assist with administrative tasks, instructional design, and evaluation. Overall, they enable teachers to focus more on developing creativity, problem-solving skills, and student competencies.

3 Application of Generative Artificial Intelligence in Descriptive Geometry

The primary aim of descriptive geometry is to provide a precise representation of three-dimensional objects and their spatial relationships on a two-dimensional plane and to enable the reconstruction and interpretation of spatial forms from planar drawings. This process is non-trivial, as it requires well-developed spatial visualization and spatial reasoning skills. Operations such as rotations, reflections, truncations, or the

transformation of geometric objects often require the ability to mentally manipulate objects in space.

In this context, 3D modeling software can play an important role by helping students and designers to better understand and visualize spatial transformations. At the same time, the integration of artificial intelligence into design environments remains challenging, as such systems require extensive training data and highly sophisticated computational models.

One notable example is Project Bernini, an experimental generative AI model developed in 2025. The model can generate 3D forms from various inputs, including text descriptions, single images, sketches, voxels and point clouds, as well as text-and-sketch combinations. The long-term goal of Project Bernini is to generate functional 3D models that can be applied in fields such as architecture, product design, entertainment, and other creative and engineering domains.

The Autodesk AI Lab at Autodesk Research trained the Bernini model on a dataset of approximately ten million diverse 3D shapes. The model was developed using more than three billion machine learning parameters and a composite dataset that included publicly available sources, CAD models, and organically shaped geometries. Despite its advanced capabilities, Project Bernini remains an experimental research initiative, and it is not currently available as a commercial product.

4 4-step model for developing spatial abilities in Descriptive Geometry in higher education

Many first-year students enrolled in various BSc engineering pro-grammes at the University of Miskolc study Descriptive Geometry as part of their education program. After completing a one-semester course in Descriptive Geometry, students in Mechanical Engineering, Environmental Engineering, and Petroleum Engineering continue with courses in Technical Drawing and Computer-Aided Design (CAD). Successful completion of these subjects requires both adequate prior knowledge and a well-developed level of spatial visualization skills; without these competencies, students often encounter significant difficulties.

Two years ago, based on our teaching experience, we concluded that changes were needed not only in the delivery of lectures, but also in the design of practical exercises and the overall instructional methodology. In collaboration with colleagues from the University of Debrecen, we investigated and discussed potential solutions at several national and international conferences.

Building on these experiences, several methodological innovations were introduced on an experimental basis in September 2025 in my first-year Environmental Engineering and Petroleum Engineering classes consisting of 46 students. This paper presents and evaluates the outcomes of these methodological changes.

4.1 About the 4-step model

A joint research project between the University of Miskolc and the University of Debrecen has led to the development of a multi-stage instructional model aimed at improving engineering students' spatial abilities in Descriptive Geometry. The model combines diagnostic assessment, targeted course adaptation, collaborative learning, and iterative curriculum development.

The individual phases of the 4-step model introduced in September 2025 in the descriptive geometry course for environmental engineering and petroleum engineering students at the University of Miskolc are as follows:

In Step 1, incoming students complete a paper-based diagnostic pre-test to assess their initial spatial visualization skills and prior knowledge.

In Step 2, following the evaluation of the pre-test, the semester schedule for the descriptive geometry course will be optimized, taking the following into account:

• In the first week of the semester, students acquire theoretical knowledge of the concept of space, geometric shapes, and spatial relationships, while addressing the gaps identified in their pre-test results,

• In the second week of the semester, students create freehand sketches from various perspectives to develop their manual dexterity and spatial visualization skills; here, they are also introduced to various axonometric projections

• By the third week of the semester, groups of 5–6 students are formed based on the pre-test taken at the beginning of the year, consisting of a mix of students who scored higher and lower on the initial test. Throughout the semester, the groups are assigned several collaborative tasks, the results of which are presented in the form of short presentations during class. If outstanding projects are developed, students will also have the opportunity to participate in the university's TDK (Student Research Society) competition.

In Step 3, we conduct the end-of-semester summative assessment using tasks similar to those in the initial test, so that we can compare the progress of students in the experimental and control groups—who were selected at the beginning of the semester and did not participate in the 4-step model.

In Step 4, taking into account the results of the end-of-semester assessment test, the curriculum for the following semesters will be developed based on these results.

This type of 4-step instruction plays a role in the gradual development of spatial perception, while also contributing to the reduction of dropout rates through a structured, phased learning approach. Universities provide an optimal environment for the integrated development of theoretical knowledge and practical competencies, where conceptual knowledge is continuously reinforced through applied tasks. Using this model, the gradual progression from basic principles to increasingly complex problems allows students to build a solid cognitive foundation, thereby improving their preparedness for advanced and multifaceted design challenges. This specific structure also takes into account different learning preferences and supports the use of a wide variety of representational and technical tools, ranging from hand-drawing techniques to advanced digital modeling and design software.

Furthermore, such a multi-level educational framework mirrors real-world professional conditions by gradually increasing task complexity and performance expectations, fostering both collaborative and competitive dynamics among students. Overall, this approach contributes not only to deeper conceptual mastery but also personal and professional development, enhancing adaptability, self-awareness, and readiness for interdisciplinary work environments [15].

Although certain pedagogical elements of the proposed model—such as assessment at the beginning of the semester, aligning curriculum planning with these results, collaborative learning, and the use of an end-of-semester retest—have been described separately in previous educational research, the originality of the proposed framework lies in its systematic integration of these elements into a descriptive geometric educational model through visualization and error analysis supported by generative artificial intelligence. The model does not introduce any new teaching techniques, but rather combines the listed elements into an integrated methodology aimed at developing students' spatial and critical thinking skills.

4.2 Baseline Assessment of Spatial Visualization Skills

The results reported in this study were obtained from an experimental group of 46 students in September 2025. Students' spatial abilities were evaluated using a diagnostic pre-test consisting of tasks adapted from several internationally validated and widely used task lists which contained a set of exercises compiled from the spatial visualization test. The selected tasks measured competencies that are fundamental requirements for the successful completion of the Descriptive Geometry course.

Types of tasks:

- Imagined manipulation of objects

This task requires the mental simulation of sequential actions performed on an object, without physical execution.

- Mental rotation of three-dimensional objects

This involves identifying objects by mentally transforming spatial representations from different viewpoints [3].

Description of tasks

- MCT (Mental Cutting Test)

The MCT measures spatial visualization skills through tasks involving the inter-section of polyhedral and planes. It consists of five items (maximum score: 5) and measures the accuracy of mental 3D representation and object recognition.

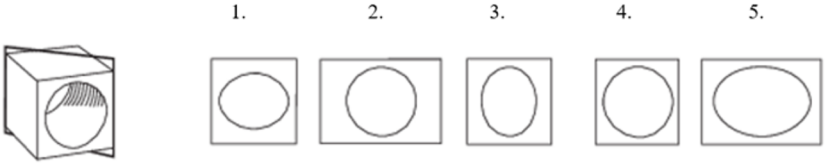


Fig. 1. Sample of MCT Test [17].

- Task I.

This task examines mental manipulation of 3D objects. Participants follow a sequence of spatial transformations and, in a subtask, identify cubes that are identical to a reference cube under rotation [17].

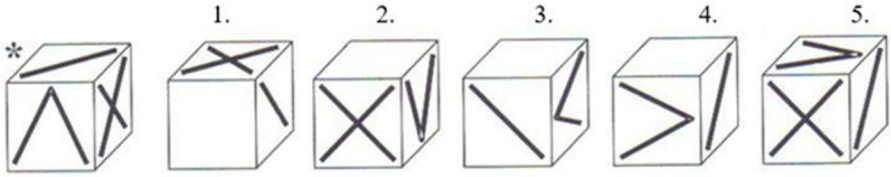


Fig. 2. Sample of task I [17].

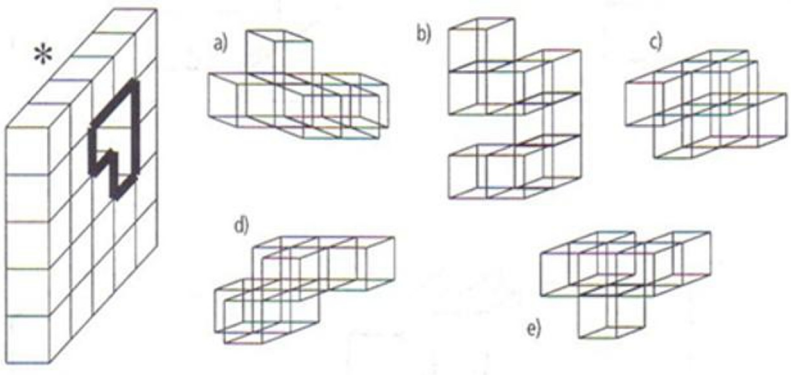


Fig. 3. Sample of task II [17].

- Task II.

In this type of task, participants were presented with five objects constructed from identical cubes, with all cube edges shown, including those that would normally be hidden from view. Their task was to identify the object that, after appropriate rotation, could pass completely through a given opening. The test included two exercises of this type, each worth 5 points, resulting in a maximum attainable score of 10 points. These tasks had been previously standardized.

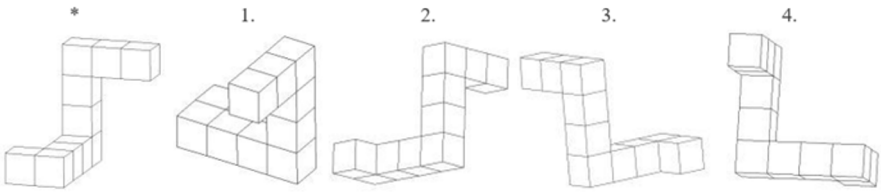


Fig. 4. Sample of MRT test [17].

- MRT test

The Mental Rotation Test (MRT) section contained six mental rotation problems. Each correctly solved exercise awarded 2 points, yielding a maximum score of 12 points.

Mental rotation ability is particularly important in Descriptive Geometry, as it supports the visualization of three-dimensional objects, the introduction of new projection planes, and the determination of visibility after geometric constructions have been completed.

During the research initiated in September 2024, the spatial abilities of first-year engineering students at the University of Miskolc and the University of Debrecen were compared using various spatial tests. Figure 5 shows the test results for both universities. The aim was to explore their spatial problem-solving strategies and based on these findings, to support the targeted development of these competencies. The development program contributes to deepening students' understanding of spatial concepts, enriches their university learning experience, and prepares them for successful performance in an increasingly changing dynamic professional environment [15].

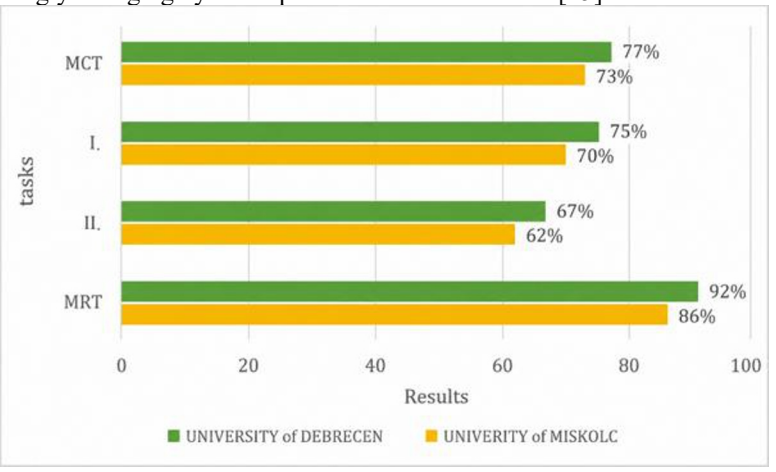


Fig. 5. The percentage distribution of test results at both universities

The sample sizes were unequal, comprising 80 first-year engineering students at the University of Debrecen and 46 at the University of Miskolc. The detailed results of the test have been analyzed and will be presented in an article that is forthcoming soon.

The survey was conducted among 46 first-year students. In contrast, the control group studied the same curriculum but exclusively using traditional methods. We did not apply the four-step model, group work, or generative artificial intelligence with this group. The control group consisted of 32 students, all of whom were mechanical engineering students at the University of Miskolc. At the beginning of the year, we administered a pre-test to them to assess their spatial reasoning, which was identical to the test given to the group of 46 students. On the pre-test, the difference between the two groups was 4–5% for all task types, indicating that there was no significant difference in their existing knowledge. At the end of the semester, we repeated the test, and the results of the 32-person control group were significantly lower than those of the 46-person experimental group. The results are summarized below: on the MCT test, nearly 23% of them performed worse on the retest; nearly 17% performed worse on both Task Types I and II; and performance on the MRT test tasks was 12% lower (it should be

noted here that these tasks had originally been performed well). Regarding completion of the descriptive geometry course taken during the semester, 6 fewer students in the control group completed the course than in the experimental group, which represents approximately 18.75% of the total group size. This result is also significant in terms of reducing the dropout rate.

4.3 Application of Generative Artificial Intelligence in the Development of Spatial Thinking: An Intervention and Outcome Study

After analyzing the results of the diagnostic pre-test, it was found that the students performed quite well on tasks involving the mental rotation of three-dimensional shapes and the comparison of figures drawn from different viewpoints. In contrast, they achieved significantly poorer results in determining the cross-sections of the bodies. Based on these findings, both the first practical session and the introductory theoretical lecture focused primarily on improving this more difficult-to-master area. We completed numerous exercises designed to develop these skills. We started from the very basics, beginning with the definition of curves, and worked through the material step by step. PowerPoint slides and three-dimensional rotating cross-sectional diagrams helped facilitate understanding. In addition to the lecture, students received all relevant course materials in a group on the University of Miskolc's closed e-learning platform. Practice exercises were also uploaded there and assigned as homework. During the classes, students were required to work in groups on several occasions, which proved to be effective; the combination of different perspectives and skills proved to be an advantage in solving problems. Whereas approximately 30% of the student group (46 students) failed when asked to complete a task individually, this failure rate dropped to less than 10% after working in teams. During the group work, following a brief discussion, they had to justify, for example, the correct solution regarding the cross-sections of the given shapes, and explain why the other solutions were incorrect. This approach not only helped to address the identified learning difficulties but also contributed to the development of teamwork skills, which are becoming increasingly important in a professional setting.

At this stage of the course, generative artificial intelligence has also been introduced by the instructors as a tool to support the learning process. AI tools have proven particularly useful in generating visual representations and in creating intentionally incorrect solution variants, thereby helping to develop students' spatial thinking skills.

To ensure equal participation, every student in each group was required to present at least one solution, so that everyone actively contributed to solving the problem. This learning process was followed by a short post-test designed to assess learning outcomes. The results showed a clear improvement: while the initial assessment showed a 40% success rate on 1-1 tasks, the retest showed that correct solutions for these tasks improved to 85%. Although generative artificial intelligence provided valuable support through visualization and error analysis, the observed improvement cannot be attributed solely to the use of artificial intelligence. The intervention also included targeted adjustments to the curriculum, supplemental practice, and collaborative group work, all of which contributed to the observed improvement in learning outcomes.

These results also called for a reevaluation of the assessment process. Since both the pre-test and the post-test were administered in paper-based form, grading proved to be time-consuming. Accordingly, it was decided that starting in the next academic year, these tests will be administered within the course's e-learning environment. This change is expected to significantly reduce the time spent on grading, as the use of a pre-compiled question bank and predetermined correct answers allows for automatic, immediate evaluation.

4.4 The Impact of Artificial Intelligence on the Fundamentals of Teaching Descriptive Geometry

In the age of artificial intelligence, the pedagogical focus in the teaching of descriptive geometry undergoes a gradual but fundamental transformation. Instead of mechanical, step-by-step construction methods, there is an increasing emphasis on geometric thinking, problem-solving, and critical analysis. As a result, the subject is gradually evolving into a competency-based field aimed at developing students' decision-making skills and professional responsibility. In this sense, descriptive geometry goes beyond the acquisition of technical skills and contributes to the development of a structured way of thinking. It encourages students to critically examine geometric models, considering why a given form is the way it is, what consequences certain geometric decisions entail, and how the models behave under different conditions.
Methodological implications for teaching:

This shift in pedagogical focus requires methodological renewal. It is therefore advisable to systematically supplement traditional, procedural, step-by-step writing exercises with problem-centered and project-based learning approaches. In particular, the analysis of AI-generated models offers a valuable opportunity to develop students' critical and evaluative competencies. In this changing educational environment, the role of the instructor is also being rede-fined: instead of merely imparting knowledge, they increasingly take on the role of a mentor who supports students in interpreting and critically examining AI-generated solutions.

Throughout the semester, after reviewing each section of the course material, students were tasked with identifying errors in various AI-generated images following a detailed analysis of the figures. One such figure was presented at the beginning of the semester, after the course requirements had been explained and the principles of Monge projection as well as the representation of its basic elements. Within a few minutes, the students successfully identified the error in the depiction of the skew lines. During the subsequent discussion, however, more informal, playful reactions also emerged, particularly regarding the interpretation of the evaluation thresholds. The infographic presented during the class is shown in Fig. 6. As a homework assignment students were then tasked with creating a similar infographic one that was geometrically and conceptually flawless using some form of generative AI.

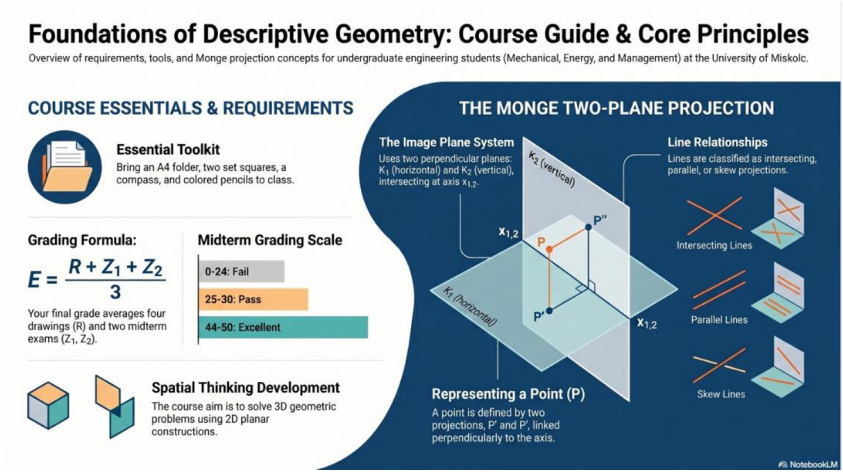


Fig. 6. The image presented during the session was generated with the assistance of NotebookLM.

4.5 Results of the educational experiment: Identifying AI-generated errors and the effects of collaborative learning in the teaching of descriptive geometry

During the semester, numerous project-based and teamwork-oriented learning activities were carried out, focusing on debugging and the critical analysis of visual representations generated by generative artificial intelligence. Students were regularly assigned tasks to present images generated by generative AI systems (including ChatGPT and NotebookLM). While they were trying to master the university-level descriptive geometry curriculum, they generated infographics that illustrated the subject's typically more difficult to understand aspects, such as the steps involved in the geometric transformations used to construct the actual sizes of shapes. These figures contained various types of geometric, construction, and interpretation errors, providing a rich basis for comparative analysis, the identification of geometric errors, and discussion of those mistakes. Students were able to gain a more nuanced understanding of the limitations and inconsistencies of AI-based geometric modeling.

As a result of these assignments 8 of the 46 students performed at a relatively low level on the diagnostic pre-test administered at the beginning of the semester, approximately 25%, but showed steady and measurable improvement throughout this period. Their average score on the end-of-semester post-test was 65%. Week by week they became increasingly active participants in the learning process, identifying geometrically incorrect constructions with growing independence and confidence. As part of their independent homework assignments, they actively searched for flawed or conceptually problematic geometric representations using various artificial intelligence tools, which contributed significantly to their continuous development.

In addition to individual development, collaborative project work also played a key role in the course. Students participated in group assignments designed both to identify

errors and to analyze diagrams and infographics generated by generative AI that correctly illustrate specific geometric operations. The best and most conceptually valuable examples of correct and incorrect AI diagrams submitted by students, along with detailed descriptions of the related geometric, construction, and interpretation errors were later uploaded to the institution's e-learning platform in the course group. This exercise created a delicate yet effective competitive environment, as students strove to produce work of increasingly high quality both in their individual and group assignments to have their work included in the shared learning collection. This dynamic did not merely foster competition; it also encouraged lasting commitment, mutual learning, and a greater sense of responsibility, as students were motivated by the opportunity to make a tangible contribution through their work to the e-learning materials available to future students. Figure 7 shows two graphics created using generative AI. One of the graphics depicts an incorrect representation of the true size of a triangle, which we discussed in class; the other is an incorrect diagram created to illustrate the cross-sections of a cone of revolution.

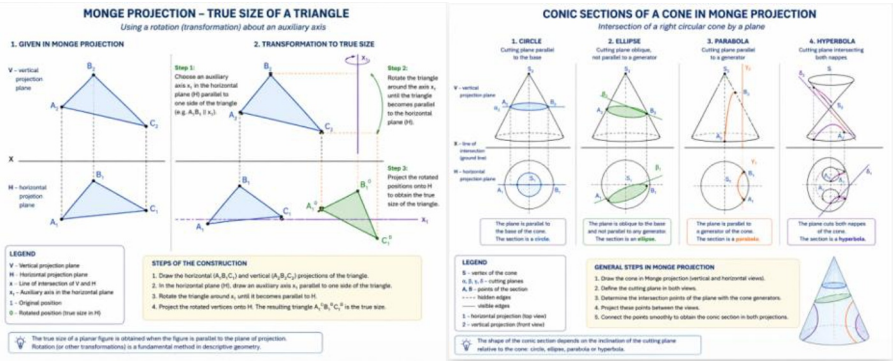


Fig. 7. Student diagrams created with the help of ChatGPT while studying true orders of magnitude and conic sections

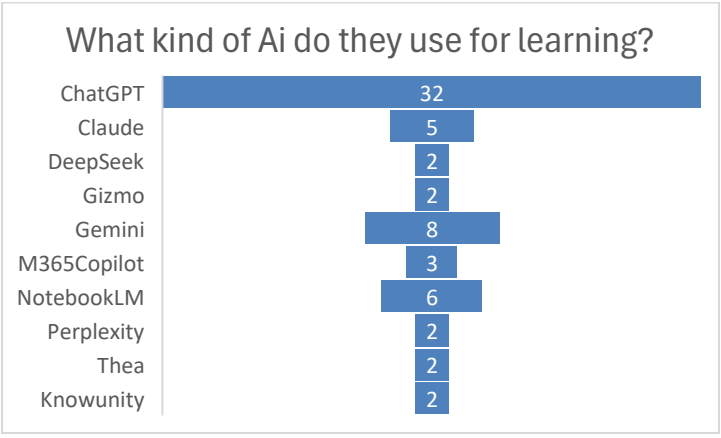


Fig. 8. Answers to questions about AI types

At the end of the semester, we wanted to find out what types of artificial intelligence the students had used during this period. The responses received are shown on Fig. 8. The chart above shows the results based on their responses. It was interesting to note that several AI tools were mentioned that I have never used at all. Toward the end of the semester, we devoted a part of one of the practical sessions to having students present to each other the various artificial intelligence tools they used. As a result, most of the students gained new knowledge that they were able to apply during the end-of-semester group assignments. As part of the assignment they had to choose one of the topics discussed, briefly summarize its key points, and then create a diagram about it by using generative AI. It was right if the diagram was not perfect; because the other group's task was to find the mistakes and explain the consequences of these geometric errors.

In the next semester, following the first group assignment in which students will use artificial intelligence for the first time, it will be important to discuss which AI tools are worth using. Therefore, even those who are not yet very familiar with this field can access the information as quickly as possible.

5 Summary

This study explores the potential applications of generative artificial intelligence (GenAI) in higher education for teaching descriptive geometry. Generative AI tools, which have become widespread since 2022, have fundamentally transformed teaching, learning, and assessment methods, necessitating the development of new pedagogical approaches. The study presents a four-step educational model developed at the University of Miskolc to enhance students' spatial abilities. The first step of the model consists of a diagnostic assessment that measures students' initial spatial perception skills. This is followed by adapting the curriculum to the results, then applying collaborative tasks based on group work, and at last a final assessment and further refinement of the curriculum. A detailed evaluation of the test is included in the author's accepted but not yet published article. The results of the research show that the use of generative AI particularly through the creation of visual representations and the analysis of intentionally flawed geometric models significantly contributed to the improvement of students' spatial thinking. During the intervention, student performance improved dramatically: the rate of correct solutions increased significantly for certain types of tasks. In addition, group work and presentations also fostered collaboration skills, which is an important competency for industry. The study concludes that integrating AI into the teaching of descriptive geometry not only improves learning outcomes but also reshapes the pedagogical approach to the subject as the focus shifts from mechanical construction to critical thinking, analysis, and improving problem-solving skills.

Despite these positive effects, we must also consider that students often accept visual representations and solutions generated by artificial intelligence unconditionally. This is perhaps most emphatically illustrated by the numerous misinterpreted and geometrically incorrect diagrams presented during the semester. Furthermore, we must strive to recognize that these diagrams and illustrative drawings, which are intended to aid in

understanding the course material, do not always ensure a deep understanding of geometric relationships, even though the fundamental goal of descriptive geometry is to develop spatial thinking, mental visualization, and problem-solving skills.

Furthermore, overreliance on artificial intelligence can reduce students' independent thinking and their efforts to mentally process spatial constructions, and their creativity may take a back seat. Striking this balance poses a huge challenge for both teachers and students.

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