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# THE EFFECT OF ALGORITHMIC INSTRUCTION IN ENGINEERING GRAPHICS ON STUDENTS' INDEPENDENT PROBLEM-SOLVING SKILLS: A RANDOMIZED CONTROLLED STUDY

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**Abstract:** this study examines the effect of algorithmic instruction on students' independent problem-solving skills in engineering graphics. A randomized controlled study was conducted with 88 first-year engineering students divided into experimental and control groups. The experimental group was taught through step-by-step algorithms and short video animations, while the control group received conventional example-based instruction. The results showed that the algorithmic approach improved accuracy, solution speed, error reduction, and spatial reasoning. These findings suggest that algorithmic instruction can be an effective method for developing independent learning in engineering graphics education.

**Keywords:** engineering graphics, algorithmic instruction, problem-solving, spatial reasoning, cognitive load, engineering education.

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## Introduction

Engineering graphics and descriptive geometry are important subjects in the professional training of future engineers. These disciplines develop students' ability to imagine the shape, position, projection, transformation, and spatial relationship of objects. In engineering practice, such skills are needed for preparing technical drawings, understanding construction schemes, designing mechanical details, working with computer-aided design systems, and interpreting visual-spatial information in production processes.

However, descriptive geometry is often perceived by first-year students as one of the most difficult parts of engineering education. The reason is that students must connect abstract geometric concepts with practical drawing operations. Many students begin the course without a sufficiently developed system of spatial thinking. As a result, they may understand a particular example during the lesson but experience difficulty when solving a new task independently.

In traditional teaching, engineering graphics is often explained through finished examples or teacher demonstrations. This method is useful at the initial stage, especially when a new topic is introduced. Nevertheless, it does not always form an independent solution strategy. A student may repeat the external form of the teacher's drawing but may not fully understand the internal logic of the solution. Therefore, when a slightly changed task is given, the student often does not know where to begin. This problem is especially visible in projection tasks, intersection problems, transformations of geometric objects, and tasks requiring mental rotation.

The algorithmic approach offers a more systematic way of organizing this process. In this approach, a complex task is divided into logically connected stages. Each stage is explained as a specific action that must be performed in a certain order. The purpose of algorithmic instruction is not to give students a mechanical scheme only. Its main value is to help students understand the structure of the task, identify the initial data, determine the required construction steps, check intermediate results, and complete the final solution independently.

The theoretical basis of this approach is closely related to multimedia learning and cognitive load theory. Multimedia learning theory shows that visual information becomes more effective when it is presented in a clear, staged, and meaningful form [1]. Cognitive load theory explains that the learner's working memory has limited capacity; therefore, learning materials should be organized in a way that reduces unnecessary mental effort and directs attention to the essential structure of the problem [2]. Later studies on cognitive architecture also show that well-designed instructional procedures help learners process complex information more effectively, especially in visually intensive subjects [3]. The idea of step-by-step problem solving also has a strong methodological foundation. Pólya's classical approach emphasizes understanding the problem, planning the solution, carrying out the plan, and checking the result [4]. Although this approach was originally developed in mathematics, it is also relevant to engineering graphics. A descriptive geometry task also requires understanding the given conditions, choosing the appropriate construction method, performing the graphical operations, and verifying the correctness of the final result.

Previous studies have shown that spatial visualization is one of the important predictors of success in engineering education. Sorby demonstrated that targeted training in three-dimensional spatial skills can improve students' performance in engineering-related subjects [5]. Uttal and colleagues also concluded that spatial skills are malleable and can be developed through systematic practice [6]. These findings are important because descriptive geometry directly depends on mental rotation, spatial transformation, projection analysis, and the ability to imagine objects from different viewpoints.

From a broader pedagogical perspective, problem-solving environments should not only transmit knowledge but also help students construct solution strategies. Jonassen argued that meaningful learning occurs when students solve authentic, structured, and progressively complicated problems [7]. This idea is highly relevant to engineering graphics, where each task requires the student to move from visual perception to logical construction.

The development of graphic and spatial thinking is also connected with creative and compositional thinking. Research on composition and visual creativity shows that students' creative abilities become more active when they consciously analyze form, proportion, structure, and spatial arrangement [8]. Although engineering graphics differs from fine arts in its technical purpose, both areas require disciplined visual thinking.

Modern engineering education is increasingly linked with digital design tools, especially computer-aided design systems. Studies on AutoCAD and three-dimensional modelling show that students' ability to work effectively in digital environments depends on their understanding of spatial construction, projection logic, and modelling commands [9]. Research on AutoCAD-based teaching also confirms that digital tools become educationally effective only when they are supported by a clear methodological system and purposeful practice [10]. Similarly, innovative methods in engineering and computer graphics instruction are effective when they are directly connected with specific learning outcomes [11]. The relevance of technical visualization is not limited to classroom drawing tasks. Smart museum technologies and digital visualization systems also show the growing role of technical representation in understanding industrial history, mechanisms, and engineering processes [12]. This confirms that spatial and graphical literacy is becoming an important competence not only for engineers but also for specialists working with technical culture, digital interpretation, and educational technologies [13].

At the same time, methodological improvement in visual and technical disciplines should not be separated from general pedagogical and aesthetic foundations. Research on the application of Eastern philosophical and aesthetic ideas in artistic education shows that visual training has both technical and cultural dimensions [14]. The development of creative competencies is also considered an important basis for the professional growth of teachers in visual arts and related fields [15]. These views support the idea that engineering graphics instruction should not be reduced to mechanical drawing operations only. It should develop accuracy, independence, spatial imagination, and methodological discipline.

Despite the existing theoretical and methodological background, there is still a need for experimental evidence on the effectiveness of algorithmic instruction in descriptive geometry. Many studies discuss structured learning, spatial training, or digital graphics instruction, but fewer studies examine algorithmic teaching through a randomized controlled design. Therefore, the present study was designed to determine whether an algorithmic instructional approach can significantly improve students’ independent problem-solving skills in engineering graphics compared with a conventional example-based teaching method.

## Materials and Methods

The study was conducted as a randomized controlled trial. A total of 88 first-year students enrolled in an engineering graphics course participated in the research. The students were divided into two equal groups: an experimental group consisting of 44 students and a control group consisting of 44 students. Random assignment was carried out using a computer-generated randomization procedure. This method was used to reduce selection bias and to make the comparison between the two groups more reliable.

Before the instructional intervention, both groups completed two diagnostic assessments. The first was the Purdue Spatial Visualization Test: Rotations, which was used to evaluate students’ spatial reasoning ability. The second was a diagnostic test in descriptive geometry, prepared to assess students’ initial level of knowledge and practical problem-solving skills in the subject. The results showed no statistically significant differences between the experimental and control groups at the baseline stage. This means that the groups were comparable before the teaching intervention began.

The instructional intervention lasted six weeks. Both groups were taught by the same instructor and had the same amount of instructional time. Each group had two 90-minute sessions per week. Thus, the total instructional time for each group was 18 academic hours.

The main difference between the groups was the teaching method. In the experimental group, each descriptive geometry problem was explained through a step-by-step algorithm. The teacher first identified the given elements of the task, then explained the sequence of construction, demonstrated the logic of each step, and used short video animations to show spatial transformations more clearly. After that, students practiced solving similar tasks independently by following the algorithm and gradually reducing their dependence on teacher guidance.

In the control group, instruction was organized in a conventional manner. The teacher demonstrated sample problems, explained the main construction techniques, and students practiced by imitating the demonstrated examples. This approach reflects the method commonly used in many engineering graphics lessons. It helps students understand a particular example, but it does not always require them to formulate a general solution procedure.

After the six-week period, both groups were assessed using post-intervention tasks. The main outcome indicators were:

- problem-solving accuracy;
- solution speed;
- number of errors;
- spatial reasoning ability.

Accuracy was calculated according to the correctness of the final drawings and the logical consistency of the construction steps. Solution speed was measured by the average time required to complete the assigned tasks. Error rate was determined by counting construction, projection, analysis, and calculation-related mistakes. Spatial reasoning was assessed using the post-test version of the Purdue Spatial Visualization Test: Rotations.

The results were statistically analyzed. The level of statistical significance was determined at $p < 0.001$, and effect sizes were interpreted using Cohen's d.

## Results

The results showed a clear advantage in favor of the experimental group. The average accuracy of the experimental group reached 78.4%, while the control group achieved 59.8%. This means that the algorithmic approach produced a 31% relative improvement in accuracy. In practical terms, students who learned through algorithms were better able to identify the correct sequence of actions and complete tasks with fewer deviations from the required solution.

Solution speed also improved considerably. Students in the experimental group needed an average of 12.3 minutes to solve the assigned tasks, whereas students in the control group required 19.8 minutes. This corresponds to a 38% improvement in solution speed. The difference is pedagogically meaningful because it shows that algorithmic instruction helped students solve problems not only more correctly but also more efficiently.

The number of errors was substantially lower in the experimental group. Students taught through the algorithmic approach made an average of 2.4 errors, while students in the control group made an average of 4.4 errors. This represents a 45% reduction in errors. The most visible decrease was observed in mistakes related to analysis and construction sequence.

Spatial reasoning scores also increased more strongly in the experimental group. The experimental group achieved an average score of 26.8 points on the post-intervention spatial reasoning test, while the control group achieved 21.9 points. This indicates a 22% improvement in favor of the algorithmic approach.

| **Indicator** | **Experimental Group** | **Control Group** | **Difference** |
|---|---|---|---|
| Accuracy (%) | 78.4% | 59.8% | +31% |
| Solution Speed (minutes) | 12.3 minutes | 19.8 minutes | -38% |
| Number of Errors | 2.4 | 4.4 | -45% |
| Spatial Reasoning (PSVT:R) | 26.8 points | 21.9 points | +22% |

All observed differences between the groups were statistically significant at $p < 0.001$. The effect sizes were also large, with Cohen's d values ranging from 0.9 to 1.4. These indicators show that the difference between the algorithmic and conventional approaches was not accidental or weak. On the contrary, the instructional method had a strong practical effect on students' learning outcomes.

## Discussion

The findings of this study show that algorithmic instruction can significantly improve students' independent problem-solving skills in engineering graphics. The main reason for this effect is that the algorithmic approach gives students a clear structure for action. When students face a complex descriptive geometry problem without such a structure, they often spend much mental effort deciding where to start, which line to draw first, how to connect the given elements, and how to check whether the drawing is correct. This unnecessary mental burden reduces their ability to understand the actual geometric relationship.

Algorithmic instruction reduces this difficulty by providing a logical sequence of operations. As a result, students can focus more on the meaning of the task rather than on random trial-and-error actions [2]. This explanation is consistent with cognitive load theory, according to which effective instruction should reduce unnecessary cognitive load and help learners focus on essential information [3]. Another important point is that the algorithmic approach does not remove independent thinking. On the contrary, it creates conditions for independence. At the beginning, students may rely on the given sequence, but after repeated practice they begin to internalize the logic of the solution. Gradually, they can adapt the algorithm to new tasks, modify the sequence when necessary, and make their own decisions more confidently. Therefore, algorithmic instruction should not be understood as mechanical memorization. Its real pedagogical value lies in transforming hidden expert procedures into visible and learnable actions.

The improvement in spatial reasoning is also significant. Spatial reasoning is not formed only by looking at drawings. It develops when students mentally follow transformations, compare positions, imagine rotations, and understand how a three-dimensional object is represented on a two-dimensional plane. In this study, short instructional video animations helped students observe how one stage leads to another and how the spatial position of an object changes during construction.

The role of video animations should be understood carefully. In descriptive geometry, many difficulties arise because students cannot imagine movement, rotation, intersection, or projection dynamically. Static drawings are sometimes insufficient for explaining these processes. Short animations can help students understand such changes. However, they must be brief, focused, and directly connected with the algorithmic steps. If animations are too long or visually overloaded, they may create additional cognitive load instead of reducing it.

The results also show that traditional example-based instruction has certain limitations. It helps students understand a given example, but it does not always develop a transferable solution strategy. Students in the control group frequently made errors at the beginning of the solution because they did not always correctly determine the first step. In contrast, students in the experimental group were more consistent in identifying the given conditions, selecting the necessary construction line, and checking intermediate results.

The study has several limitations. First, it was conducted within one university context, so the results should be generalized carefully. Second, the intervention lasted six weeks. A longer study could show whether the observed improvements remain stable over time. Third, the research focused mainly on descriptive geometry tasks. Future studies may examine whether the algorithmic approach produces similar effects in AutoCAD instruction, computer graphics, mechanical drawing, architectural graphics, or other engineering-related subjects. Despite these limitations, the results provide strong evidence that algorithmic instruction is an effective method for improving independent problem-solving in engineering graphics. The approach helped students solve tasks more accurately, more quickly, and with fewer errors. It also improved spatial reasoning ability, which is one of the essential competencies in engineering education.

## Conclusion

The present study confirms that algorithmic instruction can significantly improve students' independent problem-solving skills in engineering graphics. Compared with conventional example-based teaching, the algorithmic approach increased accuracy by 31%, improved solution speed by 38%, reduced errors by 45%, and enhanced spatial reasoning by 22%. The results were statistically significant and showed large effect sizes.

Based on the findings, algorithmic instruction may be recommended as an effective methodological approach for teaching descriptive geometry and related engineering graphics subjects. Engineering graphics teachers should divide complex tasks into clear and logically ordered stages, explain the reason for each step, encourage students to check intermediate results, and gradually lead them toward independent task completion.

Short instructional video animations may also be used to demonstrate spatial transformations, but they should be directly connected with the learning objective. The main purpose of algorithmic instruction is not to make students dependent on fixed schemes, but to teach them how to construct a reliable solution path independently.

In general, the algorithmic approach can help students move from imitation-based learning toward conscious, structured, and independent problem-solving in engineering graphics education.

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