METHODOLOGY FOR TEACHING WORKING DRAWING PREPARATION IN ENGINEERING GRAPHICS AND ITS IMPACT ON STUDENTS' GRAPHIC COMPETENCIES

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ABSTRACT. The development of graphic competencies and technical documentation skills is one of the fundamental objectives of engineering education. Working drawing preparation plays a crucial role in developing students' graphic literacy, spatial visualization abilities, and professional engineering competencies. However, many engineering students experience difficulties in interpreting technical documentation, applying engineering drawing standards, and preparing accurate working drawings.

The purpose of this study was to develop and experimentally validate an improved methodology for teaching working drawing preparation in Engineering Graphics. The research was conducted with 48 undergraduate engineering students who were divided into experimental and control groups. The proposed methodology was based on competency-based education, problem-based learning, visual modeling, collaborative learning, CAD-supported instruction, and the use of real engineering components.

The effectiveness of the methodology was evaluated through pedagogical experiments, practical graphic assignments, expert assessment, and statistical analysis. The results demonstrated significant improvements in students' graphic competencies, working drawing preparation skills, spatial visualization abilities, and technical drawing interpretation. The average performance score of the experimental group increased from 61.8 to 86.7 points, while the control group improved from 62.2 to 73.3 points. Statistical analysis using Student's *t*-test confirmed that the differences between the groups were statistically significant ($p < 0.05$).

The findings indicate that the proposed methodology contributes substantially to improving students' professional engineering competencies and graphic literacy. The study confirms the effectiveness of integrating innovative pedagogical technologies into Engineering Graphics education and provides practical recommendations for enhancing the teaching of working drawing preparation in engineering programs.

Keywords: Engineering Graphics, Working Drawing, Graphic Competence, Spatial Visualization, Engineering Education, Technical Drawing, CAD Technologies, Problem-Based Learning, Visual Modeling, Professional Competence, Engineering Drawing Standards, Pedagogical Innovation.

INTRODUCTION

The rapid development of modern engineering technologies, digital manufacturing systems, and computer-aided design environments has significantly increased the requirements for the professional training of future engineers. In contemporary engineering practice, technical documentation serves as the primary means of communication between designers, manufacturers, and engineers. Therefore, the ability to read, analyze, and prepare working drawings is considered one of the fundamental professional competencies of engineering graduates [1, p. 28].

Engineering Graphics plays a crucial role in developing students' graphical literacy, spatial visualization, and technical communication skills. Through this discipline, students acquire the knowledge and abilities necessary for representing engineering objects, interpreting technical documentation, and creating graphical information in accordance with established standards [2, p. 46]. Among the various topics included in the Engineering Graphics curriculum, the preparation of working drawings occupies a particularly important position due to its direct connection with real engineering and manufacturing activities [10, p. 72].

A working drawing is a technical document that contains complete information required for manufacturing, assembling, inspecting, and operating a product or its components. It includes geometric dimensions, tolerances, surface quality requirements, material specifications, and other technical data necessary for production processes [7, p. 311]. The ability to correctly prepare working drawings enables future engineers to transform design concepts into manufacturable products and ensures effective communication throughout the engineering lifecycle [5, p. 184].

Recent developments in industry have led to the widespread implementation of CAD technologies such as AutoCAD, SolidWorks, CATIA, Autodesk Inventor, and KOMPAS-3D. Although these technologies have transformed engineering design practices, researchers emphasize that students must first develop a solid understanding of the principles of technical drawing and working drawing preparation before effectively utilizing digital design tools [16, p. 8]. Consequently, improving the methodology of teaching working drawings remains an important challenge in engineering education [17, p. 149].

Numerous studies have demonstrated that students often encounter difficulties in interpreting engineering standards, selecting appropriate views, determining dimensions, applying tolerances, and preparing technical documentation according to accepted regulations [6, p. 263]. These difficulties negatively affect the quality of graphical assignments and hinder the development of professional engineering competencies [11, p. 128]. Therefore, there is a growing need for innovative teaching approaches that facilitate the effective acquisition of working drawing preparation skills [13, p. 45].

Modern pedagogical research highlights the effectiveness of competency-based education, problem-based learning, project-oriented instruction, visual modeling, and digital educational technologies in improving engineering graphics education [8, p. 225; 9, p. 142]. The integration of these approaches into the teaching of working drawings can enhance students' learning motivation, improve their graphical performance, and strengthen their professional readiness for engineering practice [12, p. 91].

Furthermore, current trends in engineering education emphasize the importance of developing not only technical knowledge but also analytical thinking, problem-solving abilities, and independent learning skills [18, p. 474]. Working drawing preparation provides a valuable opportunity to integrate these competencies through practical activities involving the analysis, design, and graphical representation of engineering objects [15, p. 7].

The integration of digital technologies, artificial intelligence tools, and adaptive learning systems into engineering education creates new opportunities for improving graphical training and enhancing students' professional competencies [19, p. 67]. At the same time, researchers note that traditional graphic exercises and manual preparation of working drawings continue to play a significant role in developing graphic literacy and engineering thinking [20, p. 59].

Based on these considerations, improving the methodology for teaching working drawing preparation in Engineering Graphics and investigating its impact on students' graphic competencies constitute an important scientific and pedagogical problem.

The purpose of this study is to develop and experimentally validate an improved methodology for teaching working drawing preparation in Engineering Graphics and to determine its effectiveness in enhancing students' graphic competencies, spatial visualization skills, and professional engineering readiness.

LITERATURE REVIEW

The development of graphic competencies and the improvement of engineering graphics education have attracted increasing attention in both engineering and pedagogical research. The growing complexity of engineering design processes, the widespread adoption of digital technologies, and the increasing demand for highly qualified engineering specialists have highlighted the importance of effective methods for teaching technical drawing and working drawing preparation [13, p. 44].

Researchers emphasize that graphic training represents one of the fundamental components of engineering education because it develops students' abilities to communicate technical information, visualize engineering objects, and interpret design documentation [2, p. 51]. According to Farin and Hansford, geometric thinking and graphical representation skills form the foundation of engineering problem-solving and technical communication [1, p. 42].

Numerous studies have investigated the relationship between graphic literacy and spatial visualization skills. Sorby demonstrated that students possessing well-developed spatial abilities generally achieve higher academic performance in engineering disciplines and show greater success in technical design activities [3, p. 168; 14, p. 463]. Her research further revealed that systematic graphical exercises significantly improve students' capacity to mentally manipulate three-dimensional objects and understand complex engineering structures.

The importance of working drawings within engineering practice has been widely discussed in engineering graphics literature. According to Giesecke et al., working drawings constitute the primary medium through which design concepts are translated into manufacturable products [7, p. 327]. These documents provide comprehensive information regarding dimensions, tolerances, materials, surface quality requirements, and assembly specifications necessary for production processes. Similarly, Ulrich and Eppinger emphasize that the quality of engineering documentation directly influences manufacturing efficiency and product quality [5, p. 215].

Researchers have also highlighted the educational significance of working drawing preparation. Lieu and Sorby argue that creating working drawings requires students to integrate theoretical knowledge, graphical standards, spatial reasoning, and technical communication skills into a unified professional activity [6, p. 278]. Through this process, students develop not only graphic competencies but also analytical and engineering thinking abilities.

The role of sketching and preliminary graphical representation in preparing working drawings has received considerable attention in recent studies. Eissen and Steur note that sketching enables students to analyze object geometry, identify functional elements, and establish the basis for subsequent technical documentation [4, p. 98]. These findings suggest that sketching and working drawing preparation should be viewed as interconnected stages of engineering design education.

Modern engineering education increasingly incorporates active and student-centered teaching approaches. Prince demonstrated that active learning strategies significantly improve students' understanding of technical concepts and increase their engagement in the learning process [8, p. 227]. Likewise, Felder and Brent reported that problem-based learning and collaborative educational activities contribute to the development of higher-order thinking skills and professional competencies among engineering students [9, p. 146].

Several studies have focused specifically on the effectiveness of visual modeling and project-based instruction in engineering graphics education. Researchers have found that students achieve better learning outcomes when graphic tasks are connected to real engineering situations and practical design problems [15, p. 9]. Such approaches encourage students to apply theoretical knowledge in realistic professional contexts.

The rapid development of CAD technologies has transformed both engineering practice and engineering education. Branoff reported that solid modeling environments significantly enhance students' spatial visualization skills and improve their understanding of engineering geometry [16, p. 9]. Similarly, Strong and Smith concluded that integrating CAD systems into engineering graphics courses contributes to the development of contemporary professional competencies required by industry [17, p. 153].

However, many researchers emphasize that digital tools should complement rather than replace traditional graphical training. According to Ro'ziyev and Axmedov, students who possess strong foundations in manual drawing and working drawing preparation demonstrate greater success when transitioning to computer-aided design environments [11, p. 136]. This conclusion is supported by Shomirzayev, who argues that understanding graphical standards and technical documentation principles remains essential regardless of technological advancements [10, p. 91].

Recent investigations have also explored the educational potential of virtual reality, augmented reality, and immersive visualization technologies. Martín-Gutiérrez et al. found that virtual environments improve students' comprehension of spatial relationships and facilitate the visualization of complex engineering objects [18, p. 478]. These technologies provide additional opportunities for enhancing engineering graphics instruction and improving learning outcomes.

Artificial intelligence technologies are increasingly being integrated into engineering education. Holmes, Bialik, and Fadel emphasize that adaptive learning systems, intelligent tutoring technologies, and automated feedback mechanisms can support individualized learning and improve students' academic performance [19,

p. 81]. Nevertheless, researchers generally agree that AI-based educational tools should be used as supplementary resources rather than substitutes for practical graphical activities.

Studies conducted by Uzbek researchers have also contributed to the development of engineering graphics teaching methodology. Yuldashev investigated approaches for developing graphic competencies among university students and highlighted the importance of practical graphical assignments in professional training [12, p. 92]. Recent research by Radjabov and Boymuratov demonstrated the effectiveness of innovative pedagogical technologies in improving students’ graphical literacy and learning motivation within engineering graphics courses [20, p. 60].

The analysis of the reviewed literature indicates that working drawing preparation plays a critical role in the development of graphic competencies, spatial visualization abilities, and professional engineering skills. At the same time, most existing studies primarily focus on technical aspects of engineering graphics or the application of digital technologies. Relatively limited attention has been devoted to developing and experimentally validating comprehensive pedagogical methodologies specifically aimed at teaching working drawing preparation and evaluating their impact on students’ graphic competencies.

Therefore, there remains a need for further research focused on improving the methodology of teaching working drawing preparation through innovative pedagogical approaches and assessing its effectiveness in enhancing students’ professional competencies in engineering education.

RESEARCH METHODOLOGY

The present study was conducted to develop and experimentally validate an improved methodology for teaching working drawing preparation in Engineering Graphics and to determine its effectiveness in enhancing students’ graphic competencies, spatial visualization abilities, and professional engineering skills.

The research was carried out at Karshi State Technical University among undergraduate students enrolled in engineering programs. A total of 48 students participated in the pedagogical experiment. The participants were divided into two equal groups: Experimental Group (EG**)** – 24 students; Control Group (CG) – 24 students.

Both groups studied according to the same Engineering Graphics curriculum. The difference was that the experimental group was taught the topic of Working Drawing Preparation using the developed innovative methodology, while the control group received instruction through traditional teaching methods.

The study was conducted in three consecutive stages.

Stage I. Diagnostic Assessment

The initial stage focused on determining students' baseline levels of graphic competence, spatial visualization ability, and technical drawing skills.

At this stage, students completed theoretical tests covering engineering graphics standards, technical drawing principles, dimensioning rules, tolerances, and drawing conventions. Practical graphic assignments were also administered to evaluate their ability to prepare working drawings, select appropriate views, apply dimensions correctly, and interpret technical documentation.

Pedagogical observations, interviews, and questionnaires were employed to investigate students' learning motivation, attitudes toward Engineering Graphics, and difficulties encountered during working drawing preparation.

The analysis of the diagnostic results indicated that there were no statistically significant differences between the experimental and control groups at the beginning of the study, ensuring the comparability of the groups for subsequent experimental procedures.

Stage II. Formative Experiment

During the formative stage, an improved methodology for teaching working drawing preparation was implemented in the experimental group.

The methodology was based on the principles of competency-based education, problem-based learning, visual modeling, project-oriented instruction, and interactive pedagogical technologies.

Several instructional strategies were integrated into the learning process:

Problem-Based Learning

Students were presented with engineering situations requiring the preparation of complete working drawings based on given design conditions. They were encouraged to identify technical requirements, select appropriate drawing views, determine dimensions, and independently develop graphical solutions.

Visual Modeling

Visual teaching materials, three-dimensional models, sectional representations, and assembly components were used to facilitate students' understanding of object geometry and technical structures. These resources enabled students to establish relationships between three-dimensional objects and their two-dimensional graphical representations.

Real Engineering Components

Practical activities were organized using real machine parts and engineering products. Students analyzed the geometric characteristics of these objects and prepared working drawings according to engineering drawing standards.

CAD-Based Activities

Computer-aided design software, including AutoCAD and SolidWorks, was incorporated into selected instructional activities. Students compared manually prepared drawings with computer-generated models and examined the relationship between traditional drafting principles and digital design environments.

Collaborative Learning

A number of activities were conducted in small groups. Students discussed graphical solutions, analyzed drawing errors, and collaboratively solved engineering graphics problems. This approach promoted communication skills and professional teamwork competencies.

Reflective Assessment

At the conclusion of each instructional session, students participated in reflective discussions aimed at analyzing common drawing mistakes, evaluating completed assignments, and identifying opportunities for improvement.

The control group studied the same topic using conventional explanatory and demonstration-based instructional methods without the systematic implementation of the innovative pedagogical approaches described above.

Stage III. Final Evaluation

After completing the formative experiment, students in both groups were reassessed using the same diagnostic instruments applied during the initial stage.

The final evaluation focused on measuring changes in:

- Theoretical knowledge of engineering drawing standards;
- Working drawing preparation skills;
- Graphic literacy;
- Spatial visualization ability;
- Accuracy of technical drawing execution;
- Speed of completing graphic assignments;
- Professional graphic competencies.

Students' completed working drawings were evaluated by expert instructors according to predetermined criteria.

Assessment Criteria

The following criteria were developed to evaluate students' graphic competencies related to working drawing preparation.

No.	Assessment Indicator	Maximum Score
1	Theoretical knowledge of engineering drawing standards	20

No.	Assessment Indicator	Maximum Score
2	Accuracy of working drawing preparation	25
3	Correct application of dimensions and technical requirements	20
4	Spatial visualization ability	15
5	Ability to read and interpret technical drawings	10
6	Speed of task completion	10
Total		**100**

According to the obtained scores, students were classified into four performance levels: **86–100 points** – High; **71–85 points** – Good; **55–70 points** – Satisfactory; **0–54 points** – Low.

Research Methods

The following scientific and pedagogical methods were employed:

- Analysis of scientific and methodological literature;
- Pedagogical observation;
- Interviews and questionnaires;
- Achievement testing;
- Practical graphic assignments;
- Expert evaluation;
- Pedagogical experiment;
- Mathematical and statistical analysis.

Statistical Analysis

To determine the reliability of the obtained results, several statistical methods were applied:

- Arithmetic mean;
- Variance;

- Standard deviation;
- Percentage analysis;
- Student's *t*-test.

The statistical significance of differences between the experimental and control groups was evaluated at a confidence level of **$p < 0.05$**.

The application of these methods made it possible to objectively assess the effectiveness of the proposed methodology and determine its impact on the development of students' graphic competencies and professional engineering readiness.

RESULTS AND DISCUSSION

Following the completion of the pedagogical experiment, students in both the experimental and control groups were reassessed to determine changes in their graphic competencies, working drawing preparation skills, and spatial visualization abilities. The obtained results provided evidence regarding the effectiveness of the proposed methodology.

Table 1. Average Results of Students in the Experimental and Control Groups (100-Point Scale)

Indicators	Before Experiment (EG)	After Experiment (EG)	Improvement (%)	Before Experiment (CG)	After Experiment (CG)	Improvement (%)
Theoretical Knowledge	63.4	85.8	35.3	63.7	73.4	15.2
Working Drawing Preparation Accuracy	58.7	88.9	51.4	59.2	73.8	24.7

Indicators	**Before Experiment (EG)**	**After Experiment (EG)**	**Improvement (%)**	**Before Experiment (CG)**	**After Experiment (CG)**	**Improvement (%)**
Application of Dimensions and Technical Requirements	60.2	87.4	45.2	60.6	73.1	20.6
Spatial Visualization Ability	61.5	86.2	40.2	61.8	72.4	17.2
Technical Drawing Reading Skills	62.8	87.1	38.7	63.1	73.6	16.6
Task Completion Speed	64.3	84.5	31.4	64.7	73.5	13.6
Average	**61.8**	**86.7**	**40.3**	**62.2**	**73.3**	**17.8**

The results presented in Table 1 indicate substantial improvements across all assessment indicators in the experimental group. The most significant increase was observed in working drawing preparation accuracy (51.4%), followed by the correct application of dimensions and technical requirements (45.2%), and spatial visualization ability (40.2%).

Although students in the control group also demonstrated positive progress, the magnitude of improvement was considerably lower. This suggests that the proposed instructional methodology contributed significantly to the enhancement of students' professional graphic competencies.

Particularly noteworthy was the improvement in students' ability to prepare complete working drawings in accordance with engineering standards. After the implementation of the methodology, students demonstrated greater accuracy in selecting drawing views, applying dimensions, representing sectional views, and indicating technical specifications.

Statistical Analysis Results

To determine whether the observed differences between the experimental and control groups were statistically significant, Student's *t*-test was applied.

Table 2. Statistical Comparison of Experimental and Control Group Results

Group	n	Mean (M)	Standard Deviation (SD)
Experimental Group	24	86.7	5.9
Control Group	24	73.3	6.8

The statistical calculations yielded the following results: $t = 7.35$; Degrees of freedom (df) = 46; Critical value ($\alpha = 0.05$): $t_{0.05} = 2.013$.

Since **7.35 > 2.013**, the difference between the performance of the experimental and control groups was found to be statistically significant (**$p < 0.05$**). These findings confirm that the observed improvements cannot be attributed to random variation and provide evidence supporting the effectiveness of the proposed methodology.

Analysis of Students' Graphic Errors

During the diagnostic stage, several common errors were identified in students' working drawings:

- Incorrect selection of principal and auxiliary views;

- Incomplete representation of object geometry;
- Errors in dimension placement;
- Violations of engineering drawing standards;
- Incorrect application of sectional and auxiliary views;
- Omission of technical specifications and annotations;
- Difficulties in interpreting complex engineering components.

Following the implementation of the improved methodology, the frequency of these errors decreased considerably in the experimental group. Students demonstrated greater confidence in preparing technical documentation and showed improved understanding of engineering drawing standards.

Discussion

The findings of this study indicate that the integration of innovative pedagogical approaches into the teaching of working drawing preparation significantly improves students' graphic competencies. The effectiveness of the methodology can be attributed to several factors.

First, problem-based learning activities encouraged students to actively engage in engineering problem-solving rather than passively reproducing drawing procedures. This approach enhanced analytical thinking and promoted deeper understanding of technical documentation requirements.

Second, visual modeling techniques and the use of real engineering components enabled students to establish stronger connections between three-dimensional objects and their graphical representations. These activities contributed substantially to the development of spatial visualization abilities.

Third, the incorporation of CAD technologies helped students understand the relationship between traditional engineering drawing principles and modern digital design environments. This integration increased learning motivation and strengthened professional relevance.

The findings are consistent with previous studies conducted by Sorby, Branoff, Prince, and other researchers who reported positive relationships between visual-spatial activities, active learning strategies, and the development of engineering competencies [3; 8; 14; 16].

Overall, the results demonstrate that the proposed methodology provides an effective framework for improving the teaching of working drawing preparation and contributes significantly to the development of students' graphic literacy, spatial thinking, and professional engineering competencies.

CONCLUSION AND RECOMMENDATIONS

Conclusion. The present study developed and experimentally validated an improved methodology for teaching working drawing preparation **in Engineering Graphics. The proposed methodology was specifically designed to enhance students' graphic competencies, spatial visualization abilities, and professional engineering skills through the integration of modern pedagogical approaches and practical engineering activities.**

The findings of the pedagogical experiment demonstrated that the application of problem-based learning, visual modeling, real engineering components, collaborative learning activities, CAD-supported instruction, and reflective assessment techniques significantly improved the quality of students' graphic training.

The results revealed that students in the experimental group achieved substantially higher performance than those in the control group across all evaluation criteria. Significant improvements were observed in working drawing preparation accuracy, application of dimensions and technical requirements, spatial visualization ability, technical drawing interpretation, and task completion efficiency.

The average performance score of the experimental group increased from **61.8** to **86.7** points, corresponding to an overall improvement of **40.3%**, whereas the control group demonstrated an increase from **62.2** to **73.3** points, representing an improvement of **17.8%**. These findings indicate that the proposed methodology provides more favorable conditions for the development of graphic competencies than traditional instructional approaches.

The statistical analysis performed using Student's *t*-test confirmed that the differences between the experimental and control groups were statistically significant (**$p < 0.05$**). Therefore, the effectiveness of the proposed methodology was scientifically verified.

The study further demonstrated that working drawing preparation serves not only as a technical skill but also as an important pedagogical tool for developing engineering thinking, spatial visualization, analytical reasoning, and professional communication abilities. Through systematic engagement in working drawing activities, students acquire competencies essential for modern engineering practice and industrial production environments.

Consequently, the results of the research provide scientific evidence that the application of innovative pedagogical technologies in teaching working drawing preparation contributes significantly to improving students' graphic literacy, professional competencies, and readiness for engineering practice.

Recommendations

Based on the results of the study, the following recommendations are proposed:

1. Greater emphasis should be placed on working drawing preparation within Engineering Graphics curricula, particularly through increasing the number of practical training sessions.
2. Engineering Graphics instructors should utilize real machine components, industrial products, and engineering assemblies during instructional activities to strengthen the connection between theoretical knowledge and professional practice.

3. Three-dimensional models, CAD systems, digital visualization tools, and virtual learning environments should be systematically integrated into the teaching process to enhance students' spatial visualization skills.
4. Problem-based learning, project-oriented instruction, and engineering design tasks should be incorporated into working drawing activities to develop students' analytical and professional competencies.
5. Assessment procedures should employ comprehensive evaluation criteria that include theoretical knowledge, drawing accuracy, compliance with engineering standards, spatial visualization ability, and task completion efficiency.
6. Educational institutions should encourage the integration of artificial intelligence technologies, adaptive learning platforms, and intelligent tutoring systems into Engineering Graphics education.
7. The developed methodology may be applied in various engineering programs, including Electrical Engineering, Energy Engineering, Civil Engineering, Mechanical Engineering, Technological Machinery and Equipment, and related technical disciplines.
8. Future research should investigate the impact of virtual reality, augmented reality, and artificial intelligence technologies on the development of graphic competencies and engineering design skills.

In conclusion, the implementation of the proposed methodology contributes to the modernization of Engineering Graphics education, enhances the quality of professional engineering training, and supports the preparation of highly qualified specialists capable of meeting the demands of contemporary industry.

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