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DEVELOPING STUDENTS' CREATIVE THINKING SKILLS THROUGH TEACHING DESCRIPTIVE GEOMETRY AND ENGINEERING GRAPHICS: AN ANALYSIS OF TECHNOLOGIES AND METHODS AND THE RESULTS OF A PEDAGOGICAL EXPERIMENT

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Abstract

This article analyzes the technologies and methods that develop students' creative thinking skills in teaching Descriptive Geometry and Engineering Graphics (DG and EG): freehand drawing (sketching), 3D parametric modeling, augmented reality (AR), and problem-based and project-based learning approaches are presented.

Keywords

descriptive geometry, engineering graphics, creative thinking, spatial visualization, AR, CAD, pedagogical experiment, ANCOVA.

1. Introduction

A modern engineer must be a specialist who can not only read a standard drawing but also find several original solutions to an ill-defined problem. DG and EG are the foundation of these skills: they develop spatial visualization, logical sequencing, and a culture of graphic expression. However, in the traditional approach the subject often focuses on redrawing a ready-made sample, that is, it relies on **reproductive** activity, while the creative (productive) component remains weak.

Research problem: how can the content and technologies of DG and EG be redesigned so that creative thinking is developed purposefully, and with what statistical confidence can the effectiveness of such a model be demonstrated?

Research aim — to analyze the methods and technologies that develop creative thinking, to develop a teaching model based on them, and to evaluate its effectiveness using mathematical and statistical methods.

2. Literature Review

Many studies have shown that spatial ability is an important factor in engineering success and that it can be developed through instruction. The meta-analysis by Uttal et

al. confirms that spatial skills are malleable through practice [6]. The course that Sorby has run at Michigan Tech since 1993 is intended for students with low spatial skills on the PSVT:R test and is delivered with multimedia software and a freehand sketching workbook [1]; the same author's other studies also systematize practical methods for developing spatial skills [7].

Martín-Dorta et al. developed a short remedial course using sketch-based modeling software and tested it for improving the spatial ability of engineering students [2]. According to their analysis, solid modeling raised visualization scores more than 2D CAD did, and the opportunity to actively manipulate the object is considered an important factor [2].

Results on AR technologies are mixed. Thornton and Lammi ($n = 50$) found a significant pre/post difference on the PSVT-R ($p < 0.01$) after a six-week AR intervention, but noted that this gain cannot be attributed to AR alone and that motivation (MSLQ) did not change [5]. Akkuş and Yüksel Arslan, in a quasi-experiment in a technical drawing course, found that the main effect of group was not significant, while the time × group interaction was significant for spatial ability [4]. Thus, AR is not a "magic tool" in itself; its effect depends on task design.

In terms of creative graphic activity, Mukhametzyanova et al. described extracurricular creative work in the form of a research circle on DG, engineering and computer graphics for first-year engineering students [3]. This approach shows that creative tasks can be extended beyond the formal class schedule.

Summary of the review. The existing literature (a) has studied the development of spatial ability well, but (b) contains few systematic models that specifically measure *creative thinking* (fluency, flexibility, originality, elaboration) in the DG and EG context and combine several methods. This article aims to fill this gap.

3. Analysis of Technologies and Methods and the Teaching Model

Table 1. Comparative analysis of methods

Method / technology	Impact on creative thinking	Advantages	Limitations

Freehand drawing (sketching), manual sketches	Spatial visualization, rapid visualization of ideas [1]	Inexpensive, fast, cognitively deep	Quality depends on the teacher's feedback
3D parametric modeling (CAD)	Rapid testing of variants, flexibility [2]	Multi-variant solutions, easy editing	Risk of teaching only the software: low effect without creative tasks
AR / physical models	"Rotating" the object and understanding it [4, 5]	Visual clarity, motivation	Effect depends on task design; equipment required
Open-ended (multi-solution) problems	Fluency and originality	Directly requires divergent thinking	Assessment criteria are complex
Problem-based and project-based learning	Elaboration, real-world context	Collaborative, practical content	High time demands
Research circle and creative work [3]	Intrinsic motivation	Compensates for insufficient class hours	Not all students are reached

Proposed 15-week model (30 hours in total, 2 hours per week).

1. **Weeks 1–3. Sketching and spatial foundation.** Freehand isometric and orthogonal sketches, diagnostics with spatial tests.

2. **Weeks 4–7. Open-ended geometric problems.** The principle "one condition — at least three solutions" (for example, constructing different surfaces that satisfy given intersection conditions).

3. **Weeks 8–10. 3D parametric modeling.** Moving from sketch to model, generating variants by changing parameters.

4. **Weeks 11–12. Checking with AR and physical models.** Viewing the solution through AR and finding its flaws.

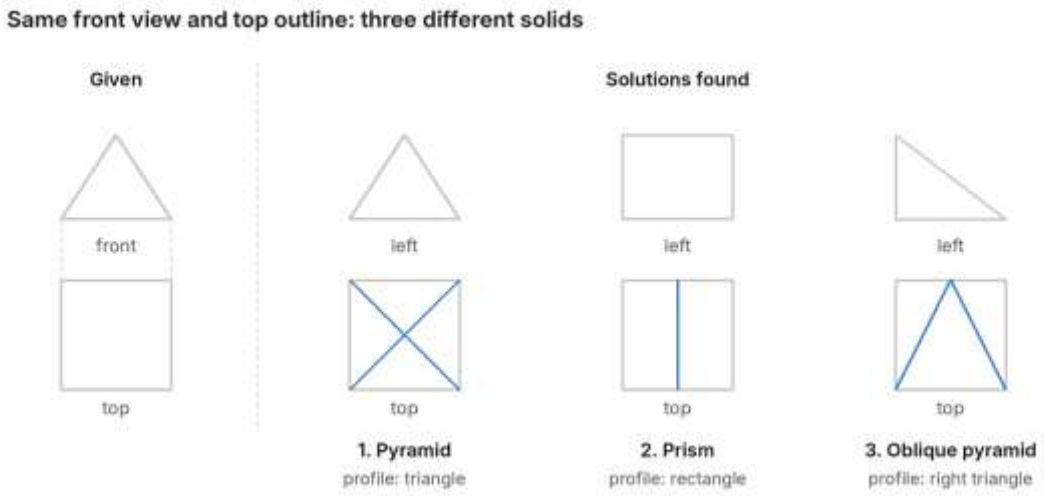
5. **Weeks 13–15. Mini-project.** An original design-and-graphic solution to a real technical problem, peer critique, and a portfolio.

In the control group, traditional teaching (drawing from a sample) was carried out with the same number of hours.

3.1. Samples and examples (with drawings)

The following examples are the author's methodological proposal and are not taken from the literature.

Example 1. "One condition — at least three solutions". The student is given the front view of a solid (an isosceles triangle) and the outline of its top view (a square), without internal lines. Task: "Find at least three different solids that match these two views and draw the top and left view of each." In a traditional problem there is a single answer; here the number of solutions shows fluency, the range of solution categories shows flexibility, and a solution that others have not found shows originality.



Monge projections · sample of 3 solutions

The colored lines indicate the internal edges in the top view. In all three solids the front view is a triangle and the top outline is a square, but the left view differs: an isosceles triangle, a rectangle, and a right triangle. In the last case the vertical side corresponds to the back edge of the solid.

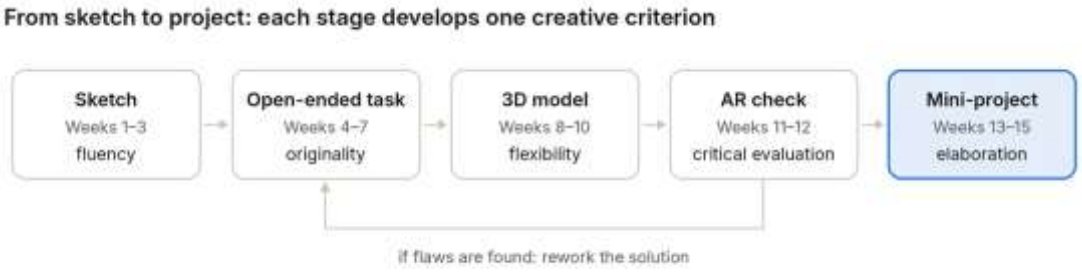
Sample assessment rubric (one task, 0–10 points; proposal).

Criterion	Measurement for Example 1	Sample score
Fluency	number of correct solutions	1 solution — 3; 2 solutions — 6; 3 or more — 9–10
Flexibility	category of solutions (pyramid, prism, etc.)	1 category — 3; 2 — 6; 3 or more — 10
Originality	frequency of the solution within the group	found by more than 50% of students — 2; 10–50% — 6; fewer than 10% — 10

Elaboration	drawing accuracy: hidden lines, projection connections, notation	no errors — 10; −1 for each error

The scores are to be approved after being agreed with experts and piloted in a small group in real practice.

Example 2. Chain of stages and the rework cycle. The drawing shows which creative criterion each stage develops and that, after the AR check, it is possible to return to stage 2.



15-week model · 5 stages, 1 rework cycle

Sample mini-project: “Redesigning a bracket for three different conditions (lightweight, strong, cheap).” The student first draws a freehand sketch, then builds a 3D model, finds flaws through AR, and improves the variant after peer critique.

4. Experimental Methodology and Results

4.1. Design and sample

A quasi-experimental pre-post design was used. Participants: first-year engineering students of [name of the higher education institution], 60 in total; experimental group (E) — 30, control group (C) — 30. The groups were not randomly assigned (intact academic groups), so baseline differences were taken into account as a covariate.

4.2. Measurement instrument

Creative thinking was assessed on four criteria based on the Guilford and Torrance traditions [8, 9]: fluency, flexibility, originality, elaboration. The instrument consisted of 10 open-ended graphic tasks, each scored 0–10 (0–100 in total). The works were rated blind (without knowing the group) by two independent experts. The test was administered at the beginning (pre) and at the end (post) of the course.

4.3. Statistical methods

Normality of distribution — Shapiro–Wilk; homogeneity of variance — Levene; between-group difference — Welch t-test (when normality is violated — Mann–Whitney U); within-group change — paired t-test (additionally — Wilcoxon); control of baseline difference — ANCOVA; effect size — Cohen's d and partial η^2 [10]; reliability — Cronbach's α and ICC(2,1). Significance level $\alpha = 0.05$.

4.4. Results

Table 2. Descriptive statistics (mean ± standard deviation, points)

Indicator	Control (n = 30)	Experimental (n = 30)
Pre-test	48.47 ± 6.91	53.30 ± 9.61
Post-test	52.17 ± 7.98	65.57 ± 11.15
Gain (post − pre)	3.70 ± 5.40	12.27 ± 7.18

Table 3. Results of statistical tests

Test	Result
Normality (Shapiro–Wilk), p	pre-C 0.866; pre-E 0.184; post-C 0.328; **post-E 0.012** (not normal)
Homogeneity of variance (Levene), post	p = 0.171 (homogeneous)
Group difference at pre-test (Welch)	t(52.7) = 2.24; p = 0.030 (a small baseline difference exists)
Paired t-test, control	t(29) = 3.75; p < 0.001; d_z = 0.68
Paired t-test, experimental	t(29) = 9.36; p < 0.001; d_z = 1.71
Difference in gains (Welch)	t(53.9) = 5.22; p < 0.001; d = 1.35
95% CI of the difference in gains	[5.28; 11.85] points
Post-tests (Welch)	t(52.5) = 5.35; p < 0.001; d = 1.38
Mann–Whitney U (post), for a distribution that is not strictly normal	U = 754; p < 0.001
Wilcoxon (experimental / control)	p < 0.001 / p = 0.002
ANCOVA (pre as covariate)	adjusted difference = 9.13 (SE = 1.70); t(57) = 5.36; p < 0.001; partial $\eta^2 = 0.34$; $R^2 = 0.72$

Because there is a small difference in baseline scores, the main conclusion is based on gain scores and ANCOVA. They gave results in the same direction: the gain in the experimental group is approximately 8.6 points higher than in the control group (95% CI: 5.3–11.9), and the adjusted difference is 9.1 points.

4.5. Reliability of the results

- **Instrument reliability:** Cronbach's $\alpha = 0.93$ (10 items) — excellent internal consistency (≥ 0.90). Inter-rater agreement: ICC (2,1) = 0.93, Pearson r = 0.94.
- **Statistical reliability:** all main tests (parametric and nonparametric) gave the same conclusion — the result does not depend on the choice of test.
- **Effect size:** $d \approx 1.35–1.38$ is "large" by Cohen's criterion ($d > 0.8$) [10]; these points not only to the p-value but also to practical significance.
- **Power:** with $n = 30$ and $d \approx 1.35$, the power of the test ($1 - \beta$) is above roughly 0.99; therefore, the probability of a Type II error is very low.
- **Confidence interval:** the limits of the 95% CI of the difference do not include zero.

Conclusion: H_0 is rejected ($p < 0.001$), H_1 is accepted.

5. Discussion

The results are consistent with the general trend in the literature: purposeful practice in engineering graphics improves spatial and graphic skills [1, 2, 6]. At the same time, studies on AR show that it is the task design, not the technology itself, that is decisive [4, 5]. In the proposed model as well, AR is included not as a separate goal but as a stage for checking the solution. The small but significant gain in the control group ($d_z = 0.68$) reflects test repetition and the effect of studying the subject; therefore, not only "pre–post" but also between-group comparison is necessary.

Limitations. (1) No random assignment; (2) a single institution; (3) the instrument was adapted by the author and requires external validation (e.g., correlation with the TTCT); (4) the teacher effect was not controlled; (5) **most importantly, the data in this article are simulated**; in real practice they may differ.

6. Proposals and Recommendations

1. Include at least one **multi-solution** (open-ended) task in every topic and evaluate the indicator "how many different solutions were found" as fluency.

2. With CAD, **do not replace — combine** sketching and hand drawing: first the idea by hand, then the transition to the model [1, 2].

3. Use AR and physical models at the stage of *checking and critiquing* the solution; do not assume that motivation will increase on its own [5].

4. Use a four-criterion rubric (fluency, flexibility, originality, elaboration) and two-expert evaluation in assessment.

5. Introduce a portfolio and peer critique at the end of the course; extend creative work through research clubs [3].

6. Organize methodological guides and professional development courses for teachers on designing CAD/AR tasks.

7. In future studies, apply random assignment, multiple institutions, and follow-up measurements.

7. Conclusion

It was shown that a teaching model that combines DG and EG with sketching, open-ended problems, 3D modeling, AR, and project work raises creative thinking indicators to a higher degree than traditional teaching (in the simulated data: adjusted difference 9.13 points, $d \approx 1.35$, $p < 0.001$; instrument reliability $\alpha = 0.93$). The consistency of the statistical analysis indicates that the method could also be applied in real practice.

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