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DEVELOPING SPATIAL VISUALIZATION THROUGH PARAMETRIC MODELING IN MECHANICAL DRAFTING AND ENGINEERING GRAPHICS EDUCATION

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Abstract

this article examines the pedagogical transformation of mechanical drafting and engineering graphics education through the integration of parametric modeling, spatial-visual reasoning, hand sketching, augmented visualization tools, and carefully scaffolded artificial intelligence support. The study argues that engineering graphics should no longer be treated as a narrow technical subject devoted only to accurate drawing, but as a cognitive, representational, and design-oriented domain in which students learn to translate between 2D and 3D forms, encode design intent, interpret manufacturing logic, and communicate technical decisions across digital environments. On the basis of recent international research, the article develops an IMRaD-structured analysis and proposes a hybrid instructional framework that combines manual projection work, explicit teaching of spatial strategies, parametric CAD modeling, AR-assisted visualization, and reflective assessment. The synthesis shows that software access alone does not guarantee conceptual understanding, while purely traditional drafting approaches cannot fully address the digital competencies required in current engineering practice. The most productive model is a sequenced hybrid pathway in which sketching, orthographic reasoning, constraints-based modeling, immersive verification, and guided digital reflection reinforce one another. The article discusses the scientific rationale, methodological structure, assessment criteria, and implementation conditions of this model.

Keywords: Engineering graphics, mechanical drafting, parametric modeling, spatial visualization, CAD, orthographic projection, AR/VR, graphic literacy, pedagogy, generative AI.

Introduction

Engineering graphics and mechanical drafting occupy a peculiar and strategically important position in modern engineering education. They are old enough to be associated with instruments, projection boards, line conventions, and classical descriptive geometry, but also new enough to sit at the crossroads of computational design, digital manufacturing, immersive visualization, and increasingly intelligent human–computer interaction. In many institutions, however, this dual nature has produced a curricular imbalance. One group of programs continues to privilege traditional drafting routines as if industrial communication had not migrated toward model-based workflows, constraints-driven assemblies, and digitally mediated collaboration. Another group moves too quickly toward software operation, assuming that proficiency in clicking commands, selecting tools, and generating visually acceptable models is equivalent to understanding geometric logic, manufacturing intent, spatial transformation, or technical communication. Both extremes are pedagogically limited. The first risks preserving procedures without preparing students for current engineering environments; the second risks producing software-dependent users who can reproduce interface sequences but cannot explain why an object is modeled in a particular way, how a projection relates to a solid, or what information is lost and gained when geometry is translated from a sketch to a parametric feature tree. Recent research reinforces the idea that the most durable learning in this area is not produced by replacing one mode with another, but by organizing a coherent developmental pathway between manual representation, spatial cognition, and digital modeling. Gutiérrez de Ravé, Gutiérrez de Ravé, and Jiménez-Hornero showed in a comparative descriptive-geometry study that hybrid teaching which combines CAD efficiency with orthographic rigor can improve conceptual understanding without abandoning the epistemic value of traditional projection systems [1]. Tiwari and Bhagat demonstrated that augmented-reality modalities in an engineering drawing course can support spatial visualization while affecting cognitive load differently depending on implementation format [2]. Lampropoulos, del Bosque, Fernández-Arias, and Vergara found in a bibliometric review of 235 studies that AR-related engineering education research has increasingly concentrated on immersive visualization, remote laboratories, motivation, and 3D modeling, indicating that graphic instruction is no longer isolated from broader digital learning ecologies [3]. Suhail, Bahroun, and Ahmed similarly concluded that augmented reality in engineering education can enrich interaction, engagement, and application, although the field still requires more disciplined integration and evaluation [4]. At the same time, spatial ability research continues to remind us that engineering graphics is not only about correctness of output but about development of internal cognitive structures. Porat and Ceobanu documented that integrated hybrid training can significantly improve the spatial ability of first-year engineering and architecture students and that such improvement is pedagogically feasible even within relatively short, well-designed interventions [5,6]. In a related study, they also showed that improved spatial ability does not influence every academic domain equally, but remains strongly tied to courses whose logic depends on visual-spatial interpretation, design reasoning, and representational transformation [7]. Wang, Ding, Wang, and Yu later confirmed that explicit instruction in spatial visualization techniques can produce significant gains among college engineering students, supporting the idea that spatial thinking should be deliberately taught rather than passively expected to emerge as a by-product of drawing practice [8]. These findings matter directly for the renewal of mechanical drafting and engineering graphics courses. The modern engineer works with dimensions, tolerances, constraints, assemblies, simulations, documentation, and increasingly with model histories that encode design intent. To function in such an environment, students must do more than produce a finished image. They must learn how a sketch governs a feature, how a feature participates in a parametric family, how orthographic views preserve or suppress information, how sectioning reveals structure, how geometric constraints embody functional relationships, and how multiple forms of representation can be coordinated across design, analysis, and manufacturing stages. Koziar and colleagues, in a systematic review of CAD use in engineering graphics education, observed that digital adoption is accelerating but remains uneven, and that curricular alignment with industry practice is decisive for meaningful implementation [9]. In parallel, recent studies on generative artificial intelligence in higher education show that technology can be educationally powerful only when accompanied by explicit scaffolding, structured prompting, and strong pedagogical framing rather than uncontrolled substitution of human thinking [10–12]. These developments create a compelling research and practice question: what kind of instructional structure can preserve the cognitive discipline of classical drafting while also cultivating the parametric, digital, and reflective competencies demanded by contemporary engineering work? The present article addresses this question by analyzing recent literature on engineering graphics, spatial ability, augmented visualization, CAD integration, and generative AI, and by proposing a pedagogical framework in which manual sketching, orthographic projection, parametric modeling, immersive verification, and guided digital reflection are organized as mutually reinforcing stages rather than competing alternatives. The objective is not to advocate a fashionable technology for its own sake, nor to defend tradition out of habit, but to clarify how mechanical drafting and engineering graphics can be redesigned as a developmental sequence that links cognition, representation, and digital production. The scientific novelty of the article lies in synthesizing several usually separated conversations—spatial ability training, descriptive geometry instruction, CAD pedagogy, AR-enhanced visualization, and AI-supported learning—into a single model oriented specifically toward engineering graphics and mechanical drafting. Its practical significance lies in offering an implementable structure for higher education instructors who wish to modernize graphic courses without sacrificing geometric understanding, representational literacy, or engineering discipline.

MATERIALS AND METHODS

The study employed a structured analytical methodology that combines document analysis, comparative pedagogical interpretation, and thematic synthesis of recent international literature relevant to engineering graphics education. Rather than claiming to present a laboratory experiment or an institution-specific intervention, the article develops an evidence-informed instructional model through critical reading and cross-comparison of current peer-reviewed sources. The core corpus was formed from studies and reviews published primarily between 2024 and 2025 in journals and proceedings focused on education sciences, engineering education, educational technology, and engineering graphics. Priority was given to sources that addressed at least one of the following categories: spatial ability development in engineering or design students, integration of CAD and orthographic projection, augmented or mixed reality in engineering visualization, systematic reviews of digital tools in engineering graphics teaching, and empirical or review-based research on pedagogically scaffolded uses of generative AI in higher education. The selected studies were not treated as isolated pieces of evidence but as nodes in a larger pedagogical problem: how to construct a sequence of learning experiences that develops both representational accuracy and cognitive flexibility. To maintain analytic rigor, the reading process proceeded through four stages. In the first stage, each source was examined for its primary object of study, methodological character, educational context, and conclusions regarding student learning. In the second stage, findings were coded according to recurring themes such as manual drawing, descriptive geometry, orthographic reasoning, spatial visualization, cognitive load, parametric logic, motivation, immersion, assessment, and scaffolding. In the third stage, sources were compared to identify productive convergences and unresolved tensions—for example, whether CAD improves conceptual understanding automatically, whether immersive media reduce or increase cognitive burden, and whether spatial ability training transfers equally across courses. In the fourth stage, the article translated these thematic findings into a pedagogical design proposal for mechanical drafting and engineering graphics. The methodological stance was interpretive but disciplined: claims were derived only when supported by more than one relevant source or when a particular study provided especially strong conceptual leverage for curriculum design. The analysis was also guided by three explicit assumptions. First, engineering graphics is both a cognitive and communicative domain; therefore, effective pedagogy must be judged not only by final products but also by the quality of reasoning that leads to them. Second, digital technologies should be understood as mediators of learning rather than autonomous solutions; the educational effect of a tool depends on sequence, scaffolding, and assessment design. Third, spatial ability is a trainable capacity that can be strengthened through targeted interventions, which means that graphic instruction should deliberately include activities aimed at mental rotation, view coordination, and 2D–3D transformation rather than assuming these capabilities will emerge spontaneously. Based on these principles, the present article synthesizes the selected literature into a design-oriented IMRaD structure. The "results" section reports the major analytical outcomes of the literature synthesis, while the "discussion" section interprets their implications for curriculum architecture, teacher action, assessment, and responsible technological integration in mechanical drafting and engineering graphics courses. This methodological choice is suitable for a field in which educational transformation often depends less on discovering a single new device than on organizing already available evidence into a coherent and transferable teaching model.

RESULTS

The synthesis produced several interrelated results that together support a strong case for redesigning engineering graphics and mechanical drafting instruction around a hybrid, staged model rather than a single dominant medium. The first result concerns the persistent centrality of spatial ability. Across recent studies, spatial ability appears not as a peripheral cognitive trait but as a foundational condition for successful engagement with orthographic views, sections, assemblies, and model interpretation. Porat and Ceobanu's studies are especially revealing because they show not only that spatial ability matters, but that it can be intentionally improved through structured interventions that mix traditional exercises, physical manipulation, and digital support [5–7]. This is pedagogically decisive. It means that educators should stop treating poor spatial performance as a fixed student deficiency and instead address it as a legitimate instructional target. In the context of mechanical drafting, this implies that exercises involving rotation, hidden geometry, cross-sections, exploded arrangements, feature recognition, and view transformation should be designed explicitly as spatial training, not merely as technical drawing tasks. The second result concerns the limits of software-only instruction. The literature does not support the simplistic assumption that exposure to CAD automatically produces deeper geometric understanding. Indeed, one of the most important messages emerging from comparative descriptive geometry research is that digital efficiency and conceptual depth do not necessarily coincide. Gutiérrez de Ravé and colleagues demonstrated that the pedagogical strength of CAD lies not in replacing projection logic but in reinforcing it when digital operations are coupled with orthographic reasoning [1]. In practical terms, students learn better when they understand how a line, plane, projection, and feature are related conceptually before those relations are automated in software. Parametric modeling becomes meaningful only when learners grasp the design intent embedded in dimensions, constraints, feature order, and parent–child dependencies. As a result, the article identifies a key instructional principle: CAD should enter the course not as an initial substitute for drawing, but as an amplifying medium introduced after core projection relationships and representational conventions have begun to stabilize in students' thinking. The third result concerns immersive technologies and their differentiated pedagogical value. The reviewed literature consistently shows that AR and related immersive tools can support visualization, engagement, and applied understanding, especially when students need help connecting flat representations to volumetric objects or when they must inspect relationships that are difficult to imagine from static views alone [2–4]. Yet the literature also reveals that not all immersive solutions are equally effective. Tiwari and Bhagat's comparison of marker-based, markerless, and web-based AR suggests that the educational gain of immersion depends on balance: too little interactivity can make the tool pedagogically thin, while too much technical or perceptual complexity can increase cognitive load and distract from the target concept [2]. This finding is crucial for engineering graphics, where the purpose of immersive media is not entertainment but representational clarification. Therefore, AR is most educationally valuable at moments of epistemic difficulty: verifying sectional interpretation, understanding assembly relationships, exploring hidden surfaces, inspecting the consequences of projection changes, or comparing alternative view sets. It should function as a temporary magnifier of spatial reasoning, not as a permanent replacement for abstract representation. The fourth result concerns the continuing value of hand sketching and explicit instruction. Recent work on spatial ability and related design fields suggests that sketching remains deeply connected to the formation of spatial thinking, especially when combined with guided explanation, gesturing, and reflective verbalization [6–8]. This does not mean nostalgic preservation of old drafting rituals for their own sake. Rather, manual sketching slows perception enough for students to notice proportional relations, edges, reference planes, and transformation steps that are often hidden behind software smoothness. When students sketch a projected object, construct an auxiliary view, or trace a sectional relationship by hand, they are forced to externalize intermediate reasoning. Wang and colleagues' findings on explicit instruction reinforce this point: direct, structured guidance in visualization techniques can significantly improve student performance, especially when learners are shown how to approach rather than merely how to answer a task [8]. Accordingly, the analysis yields a fifth result: effective engineering graphics pedagogy requires not only tasks, but also pedagogical narration. Teachers need to make their own representational thinking visible—naming rules, showing decision paths, explaining why a feature is anchored to a datum, why a section is chosen, or why a constraint order matters in a parametric model. The sixth result is the emergence of parametric logic as an educational objective in its own right. Traditional drafting focused primarily on the correct final drawing, but contemporary engineering workflows depend heavily on the internal logic of a model: parameter hierarchies, constraints, feature sequence, update behavior, associativity, and reusability. This changes what should count as competence in mechanical drafting instruction. A student who can reproduce a shape but cannot explain the modeling strategy is not yet digitally literate in a modern engineering sense. The literature on CAD integration and contemporary modeling practice suggests that parametric thinking should be taught explicitly as a form of engineering reasoning [1,9]. Students should learn that dimensions are not merely measurements to be displayed; they are variables governing design intent. Constraints are not just software options; they are formalized relationships among geometric entities. A feature tree is not a list of commands; it is a trace of decision-making. This redefinition of competence leads to a seventh result: assessment must evolve beyond static output checking. If the course only grades line quality, completed projections, or even finished 3D models, it misses the deeper educational target. A more adequate assessment structure should combine at least five dimensions: conceptual interpretation of views; quality of spatial transformation; correctness of technical conventions; integrity of parametric structure; and reflective justification of modeling or drawing decisions. Such a system aligns better with the research on spatial training, explicit instruction, and digital scaffolding because it values both process and product. The eighth result concerns the role of generative AI and related intelligent tools. The current evidence does not justify allowing AI to take over representational reasoning in engineering graphics courses; however, it does support cautious, bounded, and pedagogically structured use. Research on GenAI in engineering and higher education shows that beneficial outcomes are associated with explicit prompt training, guided tasks, and strong scaffolding rather than unrestricted substitution [10–12]. In the context of mechanical drafting, this suggests a very specific role for AI: not drawing instead of the student, but assisting explanation, error diagnosis, reflective comparison of alternative modeling strategies, generation of self-check questions, or language support for technical documentation. AI can help students articulate why a projection is incorrect, what constraint is missing, why a feature fails after regeneration, or how design intent could be preserved more robustly. Used this way, AI becomes a cognitive mirror rather than a cognitive crutch. The ninth and perhaps most integrative result of the study is the formulation of a sequenced hybrid instructional framework for engineering graphics and mechanical drafting. In Stage 1, students work with visual decomposition and freehand sketching to identify major forms, axes, symmetry, surfaces, and key reference planes. In Stage 2, they practice orthographic projection, sectional logic, and view correspondence through carefully graded tasks that require explanation as well as execution. In Stage 3, they move into parametric CAD, but the emphasis is placed not on software speed; instead it is placed on modeling strategy, feature dependency, dimension logic, and editable design intent. In Stage 4, AR or related immersive tools are introduced selectively to inspect difficult geometries, validate mental models, and reduce misinterpretation of complex spatial relations. In Stage 5, students engage in structured reflection, peer explanation, and—where appropriate—AI-assisted analysis of errors, documentation, and design alternatives. This model is not a linear ladder in the simplistic sense; learners may cycle back to sketching after digital errors, or return to projection principles when immersive inspection reveals misunderstanding. But the stages provide a developmental order that protects foundational cognition while embracing modern digital practice. Finally, the synthesis yields a tenth result concerning teacher preparation and institutional planning. Digital modernization of engineering graphics is not achieved by purchasing software licenses alone. It requires instructors who can move fluently between drawing logic, geometric explanation, software strategy, and learning psychology. It also requires assessment reform, hardware and classroom planning, time allocation for iterative practice, and curricular recognition that spatial ability development is not an optional side effect but a core educational responsibility. Thus, the true educational transformation of mechanical drafting lies less in adopting spectacular tools than in reorganizing the relationships among cognition, representation, and digital production.

DISCUSSION

The analytical results have several important implications for the theory and practice of teaching engineering graphics in higher education, especially in programs connected with mechanical engineering, machine design, manufacturing preparation, and technical communication. First, the findings challenge the widespread but shallow modernization narrative according to which adding more software automatically makes a graphics course more advanced. A course becomes truly modern not when screens replace drawing boards, but when the curriculum captures the actual representational logic of contemporary engineering work. In modern design environments, engineers move repeatedly among sketches, orthographic views, parametric models, assembly structures, simulations, annotations, revisions, and collaborative feedback. Therefore, the educational task is to teach students how these representations transform into one another and what kind of reasoning each mode supports. Manual sketching is valuable because it slows down observation and gives form to preliminary spatial thought. Orthographic drawing is valuable because it disciplines perception and teaches exact correspondence among views. Parametric modeling is valuable because it encodes design intent and reveals the dependency structure of engineered forms. AR is valuable because it offers transitional support where mental reconstruction from planar information is difficult. AI is valuable, if at all, when it supports reflection, explanation, and structured inquiry rather than replacing judgment. The central pedagogical insight is that these modes should be sequenced and integrated, not pitted against one another in curricular competition. Second, the evidence suggests that engineering graphics educators must redefine what it means to teach "accuracy." In a traditional drawing culture, accuracy usually refers to line quality, projection correctness, dimension placement, standard compliance, and neatness. These remain important. But in a parametric and digitally networked environment, accuracy also includes model robustness, associativity, logical feature ordering, disciplined naming, predictable regeneration behavior, and the ability to revise a geometry without corrupting its structure. When students learn to build a model through arbitrary steps that merely approximate the visible outcome, they are not learning engineering graphics at a professional level; they are learning cosmetic software use. This is why parametric modeling should be framed pedagogically as structured thinking. Students need to understand that a model tells a story of engineering decisions. Which sketch was created first? Which reference plane anchors the design? Which dimensions are driving variables and which are dependent? How is symmetry preserved? How can a change in one feature propagate safely through an assembly or drawing update? These questions bring the hidden logic of digital geometry into the open and make the course more intellectually honest. Third, the discussion must address transfer. One reason some educators become skeptical about spatial ability interventions is that gains are not always uniformly reflected in every course grade or every engineering subject. Yet the literature reviewed here offers a more nuanced position. Spatial ability training is most visibly beneficial in tasks and courses where representational transformation is intrinsic, such as design studio work, engineering graphics, descriptive geometry, spatial analysis, and visually mediated problem solving [5–8]. Expecting immediate transfer to all theoretical subjects is unrealistic and pedagogically unnecessary. The appropriate conclusion is not that spatial training is ineffective, but that it should be evaluated within the domains where it is causally relevant. For mechanical drafting instruction, that relevance is obvious: view generation, section interpretation, dimensional reasoning, assembly understanding, tolerance communication, and modeling strategy all rely on spatial cognition. Fourth, the reviewed studies point to the importance of cognitive load management. Digital tools are often introduced with the hope of making difficult content easier, but every new medium has its own processing demands. AR interfaces may reduce abstraction by making geometry visible, yet they can also burden students with navigation, device handling, and attention splitting. CAD may reduce repetitive manual effort, yet it can overwhelm novices with icons, command hierarchies, hidden constraints, and premature complexity. AI tools may appear to save time, yet they can create dependency, encourage superficial acceptance of plausible-sounding errors, or displace the struggle through which conceptual clarity is normally formed. The implication for curriculum design is clear: technological intensity must correspond to conceptual readiness. When students are first learning view correspondence, hidden-line logic, or sectional reasoning, the teaching environment should minimize distraction. Once core relationships are reasonably stable, digital and immersive tools can be introduced as conceptual amplifiers. This staged approach is more defensible than immediate total immersion, which often produces the illusion of progress while weakening actual comprehension. Fifth, the analysis highlights the continuing importance of the teacher as an epistemic mediator. There is a persistent temptation in contemporary education to speak as though tools teach, platforms teach, or interfaces teach. They do not. They enable, constrain, accelerate, visualize, and sometimes seduce; but teaching remains the organized act of selecting, sequencing, explaining, questioning, and evaluating. In engineering graphics, the teacher's role is especially important because much of the subject's difficulty lies in invisible transitions: from surface to edge, from edge to view, from view to section, from dimension to parameter, from feature to function. Students often fail not because they refuse effort, but because the transformation pathway remains opaque. Good instruction, therefore, must externalize reasoning. The teacher should model how to read a part before drawing it, how to choose the primary view, how to detect symmetry and reference geometry, how to anticipate sectional cuts, how to decide the order of features in a parametric model, and how to diagnose modeling failure. This is why explicit instruction remains compatible with high-level engineering education: guidance is not the enemy of independent thinking; it is often the precondition for it. Sixth, responsible AI integration deserves special attention. The current educational climate sometimes swings between hype and fear, with little room for disciplined middle positions. The reviewed evidence supports such a middle position. Generative AI can be useful when it helps students verbalize design rationale, compare alternatives, identify possible errors, or produce self-explanations under teacher supervision [10–12]. But if it is used to generate finished solutions without accountability, it undermines precisely the representational struggle through which engineering graphics builds competence. For that reason, AI policy in graphics courses should be task-specific. AI may be allowed for reflective logs, error explanation, terminology support, or feedback dialogues; it should be restricted or carefully monitored in core projection, modeling, and drawing tasks where the learning objective is direct student construction. This principle is analogous to calculator policy in mathematics: the educational acceptability of the tool depends on what is being learned. Seventh, the proposed hybrid model has practical implications for course design in the context of Uzbek higher education and similar environments where institutions may differ in software access, teacher preparedness, and digital infrastructure. The model is adaptable precisely because it does not require maximal technological saturation. Even a modestly equipped department can strengthen engineering graphics education by redesigning task sequence, foregrounding sketch-to-model transitions, using low-cost spatial exercises, embedding explicit visualization instruction, and introducing digital tools at conceptually appropriate moments. Where AR is unavailable, physical models and carefully chosen 3D viewers can serve similar bridging functions. Where AI access is limited, reflective peer explanation and annotated error analysis can fulfill much of the same pedagogical role. Thus, the framework is not dependent on luxury hardware; its core innovation lies in pedagogical architecture. Eighth, the discussion suggests that assessment reform is indispensable. If instructors continue to grade mainly final drawings, then students will adapt by optimizing appearances rather than understanding. A more valid assessment ecology would include timed sketch interpretation, oral explanation of projections, parametric editing tasks, model repair assignments, and brief reflective statements about design intent. Such assessment forms make cheating more difficult, reveal thinking more clearly, and align more closely with authentic engineering communication. Ninth, the article contributes theoretically by reframing engineering graphics as a representational ecosystem rather than a discrete course about drawing conventions. In this ecosystem, cognition, geometry, notation, software, visualization, and communication are interdependent. Educationally, this means that the goal is not to protect one medium from another, but to orchestrate transitions among them so that each medium teaches what it teaches best. The board and pencil teach economy of form and attentional discipline. Orthographic construction teaches projection logic. Parametric CAD teaches dependency and editability. Immersive visualization teaches embodied inspection of form. AI-supported reflection, when controlled, can teach metacognitive articulation. The future of mechanical drafting education will belong neither to nostalgic traditionalism nor to uncritical technological substitution, but to curricula capable of composing these strengths into a coherent developmental sequence.

CONCLUSION

The article has shown that a meaningful renewal of mechanical drafting and engineering graphics education requires more than adding new technologies to an old syllabus. The evidence synthesized from recent studies indicates that the field must be redesigned around an integrated understanding of spatial ability, projection logic, parametric thinking, selective immersive support, and guided reflective practice. Spatial visualization remains a trainable and indispensable foundation of success in graphics-related learning. Manual sketching and orthographic construction retain strong educational value because they externalize reasoning and discipline perception. Parametric CAD is essential because contemporary engineering practice depends on editable, constraints-based models that encode design intent. AR and related immersive tools are useful when deployed strategically to clarify difficult geometric relations rather than as permanent substitutes for abstraction. Generative AI can contribute only under explicit pedagogical control and should support explanation and reflection rather than replace student reasoning. On this basis, the article proposes a hybrid staged model in which students move from sketching and decomposition to projection, from projection to parametric modeling, from modeling to immersive verification, and from action to reflective analysis. The model is scientifically grounded, pedagogically coherent, and practically adaptable. Its major contribution is to show that the true modernization of engineering graphics lies in the intelligent organization of representational transitions. When students learn not just how to draw or model, but how to think across representations, they become better prepared for modern engineering design, manufacturing communication, and lifelong professional adaptation.

REFERENCES

1. Gutiérrez de Ravé, S., Gutiérrez de Ravé, E., & Jiménez-Hornero, F. J. (2025). Integrating CAD and Orthographic Projection in Descriptive Geometry Education: A Comparative Analysis with Monge's System. Education Sciences, 15(11), 1492. https://doi.org/10.3390/educsci15111492
2. Tiwari, A. S., & Bhagat, K. K. (2024). Comparative Analysis of Augmented Reality in Engineering Drawing Course: Assessing Spatial Visualization and Cognitive Load with Marker-Based, Markerless, and Web-Based Approaches. Australasian Journal of Educational Technology, 40(6), 19–36. https://doi.org/10.14742/ajet.9217
3. Lampropoulos, G., del Bosque, A., Fernández-Arias, P., & Vergara, D. (2025). Augmented Reality in Engineering Education: A Bibliometric Review. Information, 16(10), 859. https://doi.org/10.3390/info16100859
4. Suhail, N., Bahroun, Z., & Ahmed, V. (2024). Augmented reality in engineering education: enhancing learning and application. Frontiers in Virtual Reality, 5, 1461145. https://doi.org/10.3389/frvir.2024.1461145
5. Porat, R., & Ceobanu, C. (2024). Enhancing Spatial Ability: A New Integrated Hybrid Training Approach for Engineering and Architecture Students. Education Sciences, 14(6), 563. https://doi.org/10.3390/educsci14060563
6. Porat, R., & Ceobanu, C. (2024). Enhancing Spatial Ability among Undergraduate First-Year Engineering and Architecture Students. Education Sciences, 14(4), 400. https://doi.org/10.3390/educsci14040400
7. Porat, R., & Ceobanu, C. (2024). The Role of Spatial Ability in Academic Success: The Impact of the Integrated Hybrid Training Program in Architecture and Engineering Higher Education. Education Sciences, 14(11), 1237. https://doi.org/10.3390/educsci14111237
8. Wang, Q., Ding, Y., Wang, J., & Yu, Q. (2025). Explicit Instructions to Improve Spatial Visualization Skills of College Engineering Students. Journal of Civil Engineering Education, 151(4). https://doi.org/10.1061/JCEECD.EIENG-2124

9. Koziar, M., Hubal, H., Burchak, I., Botviniev, M., & Saveliev, D. (2025). The impact of CAD software on the teaching of engineering graphics: a systematic review. Periodicals of Engineering and Natural Sciences, 13(1), 17–39. https://doi.org/10.21533/pen.v13.i1.278
10. Garg, A., Soodhani, K. N., & Rajendran, R. (2025). Enhancing data analysis and programming skills through structured prompt training: The impact of generative AI in engineering education. Computers and Education: Artificial Intelligence, 8, 100380. https://doi.org/10.1016/j.caeai.2025.100380
11. Belkina, M., Daniel, S., Nikolic, S., Haque, R., Lyden, S., Neal, P., Grundy, S., & Hassan, G. M. (2025). Implementing generative AI (GenAI) in higher education: A systematic review of case studies. Computers and Education: Artificial Intelligence, 8, 100407. https://doi.org/10.1016/j.caeai.2025.100407
12. Liu, X., & Zhong, B. (2025). Integrating generative Artificial Intelligence into student learning: A systematic review from a TPACK perspective. Educational Research Review, 49, 100741. https://doi.org/10.1016/j.edurev.2025.100741.