

Developing Innovative Thinking Through Architectural Graphics: An Integrated Content-Pedagogy-Assessment Framework

Qian Ding¹, Lili Sun^{1*}

¹ School of Urban Design, Wuhan University, Wuhan, China

² Department of Gynecologic Oncology, Women's and Children's Hospital, Zhongnan Hospital of Wuhan University, Wuhan, China

Email Address

dqian@whu.edu.cn (Qian Ding), lilysun827@163.com (Lili Sun)

*Correspondence: lilysun827@163.com

Received: 15 January 2026; **Accepted:** 25 February 2026; **Published:** 2 March 2026

Abstract:

The digital intelligence era has raised expectations for students' innovative thinking in architecture and related fields. Yet Architectural Graphics education has long emphasized drafting standards and drawing skills, and it often leaves limited room for learning to think with drawings. Guided by outcomes-based education and constructive alignment, this paper proposes an integrated Content–Pedagogy–Assessment (C-P-A) framework oriented to the development of innovative thinking. innovative thinking is defined as four trainable competencies: spatial representation, diagrammatic reasoning, problem restructuring, and solution evolution. The framework uses Indicator–Task–Evidence (I-T-E) as the basic implementation unit, so that indicators, tasks, and evidence can be linked into a coherent teaching–learning–assessment loop. The curriculum is organized around three modules—Graphics Fundamentals and Spatial Cognition, Graphic Translation and Thinking Training, and Graphics Practice and Innovative Application—and teaching unit example set is presented in a healthcare-space scenario to show how the framework can be applied in course design.

Keywords:

Architectural Graphics, Innovative Thinking, Constructive Alignment, C-P-A Framework, I-T-E Unit

1. Introduction

1.1. Research background and problem statement

Artificial intelligence (AI), Building Information Modeling (BIM), and digital twins are reshaping how architectural work is carried out [1]. As software takes over parts of repetitive work, architects increasingly need to make judgments in complex situations. Therefore, Architectural Graphics should not be treated only as a tool for geometric depiction. It should also support information integration, logical reasoning,

and early-stage solution generation [2]. If Architectural Graphics education remains focused on drafting skills alone, it cannot meet these competency demands.

Architectural Graphics is often the first foundational course that architecture undergraduates take when they enter professional study. It typically centers on projection principles, drafting standards, and multi-view representation, providing an expressive base for later design studios. In many classrooms, however, the course is still treated as a “tool” class. Learning goals and assessment tend to focus on whether line types, dimensions, and sheet layout comply with standards, which leads students to put most of their effort into getting drawings “correct” and “standard-compliant.” As a result, students may produce drawings that meet formal requirements, yet still lack the ability to use diagrammatic analysis to examine problems, compare alternatives, and document their reasoning process [3].

In response to these concerns, many improvements have been made in recent years. Some courses move explanations online and use class time mainly for practice and discussion [4]. Others add BIM, VR, or new drawing software to better align with professional workflows. Yet many of these changes remain local adjustments—either to tools or to classroom organization. Key problems still lack clear solutions: How are learning goals translated into classroom activity? Beyond the formal correctness of final drawings, what evidence can capture student learning as it unfolds? How can feedback stay continuous while students are drawing? Meanwhile, many drafting courses still treat “producing standard drawings” as the main outcome, with limited task design and assessment criteria for the ability to think through drawings. Over time, students may come to see drawing as a tedious final submission, rather than as a cognitive tool architects use to test forms and refine design decisions [5].

Therefore, the central task of reform in Architectural Graphics is not simply to add new content or new tools. It is to build a sustainable course-level mechanism in which content, pedagogy, and assessment work toward the goal of innovative thinking, and are continuously adjusted through evidence and feedback.

1.2. Research gap

Existing research suggests that innovative thinking can be developed through training rather than being determined by innate talent [2]. Visual forms of expression—such as sketches and diagrams—can make thinking visible, which supports reflection and improvement [6]. In foundational courses such as engineering graphics, reforms have also drawn on Outcome-Based Education (OBE), blended learning, project-based learning (PBL), and diversified assessment to shift course aims from skill training toward competency development [7,8]. The principle of constructive alignment further argues that intended learning outcomes, learning activities, and assessment tasks need to be designed around the same goal; otherwise, isolated changes are unlikely to lead to deeper learning and higher-order capability development [9,10].

However, clear gaps remain when Architectural Graphics is considered as a foundational course in the curriculum. First, studies on constructive alignment often focus on core professional courses, while foundational courses such as graphics receive less attention. How to align learning outcomes, classroom activities, and assessment tasks in a graphics course has not been discussed in a systematic way. Second, reforms in graphics education frequently refer to “innovative capability,” but it often appears as a broad aspiration. There is still a lack of competency breakdowns

that match the characteristics of learning in graphics, as well as indicator-like descriptions that can be used for teaching and assessment. Third, even where blended learning or PBL assignments have been tried, there is still no classroom-operable framework that places innovative thinking at the center and integrates content, pedagogy, and assessment as a system.

1.3. Research aims and questions

To address these gaps, this paper takes Architectural Graphics as the study context and proposes an integrated Content–Pedagogy–Assessment (C-P-A) framework for developing innovative thinking. Rather than offering a fixed teaching script, the paper explains how the framework coordinates course operation through goal specification, task organization, and evidence-based feedback—and how this coordination can be enacted in everyday teaching.

This paper addresses the following three questions:

- (1) In Architectural Graphics, how can innovative thinking be defined and broken down into core competencies that are observable and trainable?
- (2) Guided by constructive alignment, how can an integrated C-P-A framework be built so that content, pedagogy, and assessment work together?
- (3) Within an Architectural Graphics course, how can the framework be made operable through module design and task organization, so that student competencies develop in a stepwise manner?

2. Foundations and Prior Attempts

2.1. Innovative thinking and graphics education

In recent years, Architectural Graphics education has seen growing discussion about how to develop innovative thinking. Prior work suggests that innovative thinking is not simply a matter of talent; it is closer to a set of abilities that can be developed through learning tasks and practice [2]. During graphics learning, students often generate many early ideas as they move from understanding a problem to shaping an option and revising it. If these ideas remain unexpressed, they are hard to revisit, compare, and refine. Visual tools such as diagrams and sketches can “hold” those ideas on paper, creating a basis for analysis and reflection [11].

For this reason, graphics should not be treated only as a technical means of geometric depiction. It can also serve as a medium for making thinking visible. When students use diagrammatic analysis to turn abstract spatial imagination into shareable graphic language, spatial relations can be tested on the sheet, and the line of reasoning becomes easier to show and review [12]. In teaching practice, the value of sketches, functional zoning plans, and circulation diagrams does not lie mainly in practicing a drawing technique. More importantly, these diagrams leave a record of thinking that can be discussed and inspected: judgment, key assumptions, and revision paths can be made explicit through annotations and version comparison. Consider a basic task—producing orthographic views from an axonometric drawing. Students can often follow steps and deliver standard-looking views. Yet when asked why a certain direction is chosen as the front view, or why the object is not inverted before drawing, they may only answer that they “followed the teacher’s steps.” In such cases, the drawing and the explanation do not form a traceable basis for reasoning.

2.2. Reforms in Graphics Education

In engineering graphics and other foundational courses, many recent reforms draw on Outcome-Based Education (OBE) and show a broader shift from “completing skill training” toward competency development. A common approach is to specify intended learning outcomes (competency goals) first, and then plan content, learning activities, and assessment accordingly, so that the course operates more directly toward those goals.

Some courses adopt blended learning and add diversified assessment, bringing the learning process into evaluation and extending course goals beyond drawing skills to include engineering literacy and innovative awareness [7]. The key issue, however, is not whether formative components exist, but what they actually capture. In some cases, process scores are tied to log indicators such as viewing time, quiz frequency, or attendance records. Meanwhile, assignment grading still focuses mainly on drafting standards and the correctness of the final product, which makes students’ reasoning, trade-offs, and revisions difficult to present in a stable and comparable way [13]. As a result, even when organizational formats are updated, it remains hard to show which observable graphics performances signal competency growth, and which traceable pieces of student work support that judgment.

2.3. Constructive alignment and instructional reform

From the perspective of constructive alignment, the difficulties described above become easier to explain. The theory argues that intended learning outcomes, learning activities, and assessment tasks need to be internally consistent [9]. When the three aspects do not operate toward the same competency goal, students are likely to adopt strategic approaches—putting effort into “getting through” assignments and exams rather than developing understanding and capabilities that can transfer across tasks. Alignment, however, is more than drawing lines in a matrix. Its practical core is whether assessment can generate traceable evidence of students’ learning as it unfolds, and whether that evidence is brought back into classroom discussion and subsequent instructional planning. On this basis, teachers can adjust tasks and teaching approaches, and students can revise their learning strategies—turning alignment from a principle into a course mechanism that can run over time [10].

When this logic is applied to Architectural Graphics, its relevance becomes even more apparent. If the course treats “drawing to standard” as the primary goal, assessment will naturally rely on summative drawings to judge correctness. But if the aim is to help students learn to think through drawings, classroom activities need to elicit and reveal their reasoning, and assessment must respond to the grounds on which their claims are made. A common misalignment in practice is that the same drawing task can point to very different competency goals depending on the teaching intention. It may function as practice in line types and drafting conventions, or it may be used to check whether students can explain why they drew in a certain way, where adjustments are needed, and what evidence supports those decisions. If this difference in intention is not made explicit in task requirements and evidence collection, courses can easily end up with many assignments completed but little clarity about which competencies have actually improved.

While Outcome-Based Education (OBE) emphasizes stating learning outcomes and competency goals clearly, constructive alignment focuses more on how those goals are activated through tasks and then supported—and calibrated—through evidence

and feedback. Research on engineering graphics in China also suggests that, when alignment thinking builds on OBE-style outcome statements, and when process evidence and diversified assessment are built into course arrangements, implementation becomes more consistent and more traceable. This, in turn, is more likely to support students' comprehensive innovative capability development [14].

2.4. Limitations and challenges of existing attempts

Although reforms in graphics education have taken many forms, the same operational issues often reappear at the course level. A common pattern is that once new technologies enter the classroom, the course may look more up to date, yet the underlying logic of task design remains unchanged. Building Information Modeling (BIM) and virtual reality (VR) are typical examples. In many classes, they are treated as added skills or demonstration tools. Students may learn the procedures, but they do not necessarily see how these tools connect to competency goals, and they may struggle to use them for reasoning, option comparison, and iterative refinement [15,16].

Another common strategy is blended learning. By moving explanations to the pre-class stage, it often improves resource sharing and frees more class time for practice. However, its contribution to innovative thinking is usually inferred from experience rather than supported by direct evidence. In practice, it is difficult to show that students who complete online preparation will necessarily be better at using drawing elements to analyze complex problems. In addition, blended formats require substantial platforms, resources, and instructor time. Differences in institutional conditions often constrain broader adoption [17].

Challenges are more prominent in assessment. Current assessment is still dominated by drafting standards and summative checks, while offering few workable criteria for process-oriented performance such as reasoning, restructuring, and iteration. Students' reasoning paths—what judgments guided each graphic decision, why a revision was made, or why a version was abandoned—are usually not required in submissions, and they are hard to compare or respond to through feedback [18]. When assessment focuses only on the final drawing, students naturally adopt a “get it right and submit it” strategy, and process thinking becomes marginal. For example, in producing a functional zoning plan, students can often complete the required labels. Yet when asked why the waiting area is placed in a particular location, or how this arrangement affects circulation, many respond with “it just seems reasonable.” The drawing and the explanation then fail to form traceable grounds for reasoning.

In sum, when tool adoption, organizational updates, and process-oriented assessment lack a course-level goal–task–evidence chain, they rarely develop into a stable operating mechanism. To address this, this paper proposes an integrated Content–Pedagogy–Assessment (C-P-A) framework. Guided by competency goals, it translates instructional tasks into evidence that can be collected and interpreted, and it uses that evidence to guide instructional adjustment.

3. Conceptual and Theoretical Foundations

3.1. Positioning of Architectural Graphics

Architectural Graphics has traditionally been framed as a technical foundational course, centered on projection principles and drafting standards. Design cognition

research, however, has long shown that drawings mediate thinking rather than merely record it. Schön (1983) described designing as a “reflective conversation” between the designer and the situation, in which drawings both express ideas and trigger new cognitive feedback [19]. Goldschmidt (1991) observed that people often shift between two modes when viewing sketches—“seeing-as” and “seeing-that.” The former prompts association, while the latter supports reasoning. This suggests that even rough sketches can both trigger associations and support reasoning [20]. Do and Gross (2001) further argued that drawings do not simply document thought; they actively take part in how thinking unfolds [12].

These perspectives provide a basis for rethinking the educational value of graphics courses. In Architectural Graphics, methods such as orthographic views and section drawings offer a thinking path that moves back and forth between three-dimensional spatial relations and two-dimensional representations; spatial imagination is often built through such back-and-forth translation [5]. Diagram types that address spatial program and circulation help students organize ideas into a line of reasoning that can be examined [12]. Iterative drawing also advances students' design thinking through version comparison and revision [11].

Accordingly, this paper repositions Architectural Graphics as a diagram-driven cognitive platform and offers an operational criterion. When students' drawings make three types of information explicit—grounds for judgment, diagram-based evidence, and a visible revision trail—and when these are sufficient to support critical inquiry and feedback, Architectural Graphics moves beyond technical training in representation. It becomes a form of thinking activity that advances spatial reasoning, logical structuring, and solution iteration in real or near-real spatial situations.

3.2. The principle of constructive alignment

This paper draws on constructive alignment, which argues that course design should begin with intended learning outcomes and then work backward to organize learning activities and assessment tasks, so that all three align around the same goal [9]. Building on this principle, this paper proposes an integrated Content–Pedagogy–Assessment (C-P-A) framework to operationalize alignment in Architectural Graphics. In this framework, content translates competency goals into implementable knowledge and task components; pedagogy organizes the corresponding learning activities; and assessment examines—and adjusts—course operation through collectible evidence and feedback.

The framework operates in three steps. First, intended learning outcomes are summarized as observable and assessable competency performances. This paper defines these as indicators of innovative thinking and uses them to organize course content. Second, learning activities are organized around tasks so that students make their grounds for judgment and reasoning processes visible while working. Pedagogy needs to support task enactment and match the content sequence. Third, assessment tasks collect evidence indicating whether innovative thinking is taking place, and the results are fed back into teaching to adjust content and refine pedagogy, enabling continuous adjustment of the course.

3.3. A four-dimensional competency model of innovative thinking

Drawing on Razzouk and Shute's (2012) discussion of design thinking features [21] and Kadyirov et al.'s (2024) categorization of design skills [22], and considering the

cognitive characteristics of Architectural Graphics, innovative thinking is defined as four interrelated competencies:

(1) Spatial representation: Students can rotate, decompose, and reassemble three-dimensional forms mentally, and translate this spatial understanding into two-dimensional drawings or digital models. The emphasis is on whether massing, scale, and orientation are expressed clearly enough for the drawing to be examined and discussed.

(2) Diagrammatic reasoning: Students use diagrams such as plans, functional zoning plans, and circulation diagrams to break complex design information into traceable logical relations. Using these diagrams, they analyze problems, propose design directions, and check feasibility. Here, diagrams are not only a way to present results; they also carry the reasoning process and provide grounds for decisions.

(3) Problem restructuring: Students do not stop at the surface requirements of a task brief. Through diagrammatic analysis, they probe the core of the problem, identify implicit needs and potential contradictions, and reframe the problem boundaries from a new perspective so that subsequent analysis and solution generation have a clearer direction.

(4) Solution evolution: Students treat a solution as something that evolves through iterative refinement rather than a one-off final output. They generate multiple alternatives through graphics-based moves such as version comparison, massing changes, and parameter adjustments, and then refine them step by step through comparison, analysis, and feedback.

These four competencies work together in real tasks. Spatial representation makes spatial relations visible; diagrammatic reasoning organizes scattered information into a coherent logic; problem restructuring prompts students to question deeper design intentions; and solution evolution allows ideas to mature through ongoing comparison and revision.

4. Building an Integrated C-P-A Framework for Architectural Graphics

4.1. Design principles

To ensure that the integrated Content–Pedagogy–Assessment (C-P-A) framework can both guide course goals and run reliably in everyday teaching, this paper proposes four design principles: instructional fit, innovation orientation, integrated linkage, and operability.

(1) Instructional fit. The framework is grounded in the knowledge structure and learning patterns of Architectural Graphics, so thinking training is anchored in specific concepts rather than detached from content. Course organization also needs to match the time constraints and practice rhythm of graphics classes. Assessment should rely on learning outputs that can be produced in class and can be recorded and checked.

(2) Innovation orientation. The framework treats innovative thinking as the core goal, but it does not treat “innovation” as merely a slogan. Instead, it requires observable and assessable performances—for example, students can use diagrammatic analysis to state the grounds for a judgment, and they can give comparable reasons for changes made to a solution.

(3) Integrated linkage. Content, pedagogy, and assessment are designed as a unified system aligned with the same competency goal. Within this system, indicators translate goals into observable performances; tasks organize activities accordingly and produce traceable evidence; and assessment turns evidence into feedback that informs content sequencing and instructional organization. This design helps avoid disconnection between teaching, learning, and assessment.

(4) Operability. The framework provides clear guidance on module structure, task types, and assessment evidence, but it does not prescribe teaching as a fixed script. It also treats differences in students' prior preparation and available class hours as design constraints, keeping task scope and difficulty within manageable bounds. In this way, the framework supports teaching plans that can be implemented in regular classes, reused, and adjusted to context.

4.2. Overall structure

As shown in Figure 1, the integrated Content – Pedagogy – Assessment (C-P-A) framework for Architectural Graphics operates as a coordinated system composed of content, pedagogy, and assessment. The three elements are not linked in a simple sequence. Content needs pedagogical support to become actionable learning tasks; the effectiveness of pedagogy relies on evidence generated through assessment; and assessment uses evidence produced in tasks, then feeds results back to both content and pedagogy to guide subsequent content updates and pedagogical refinement.

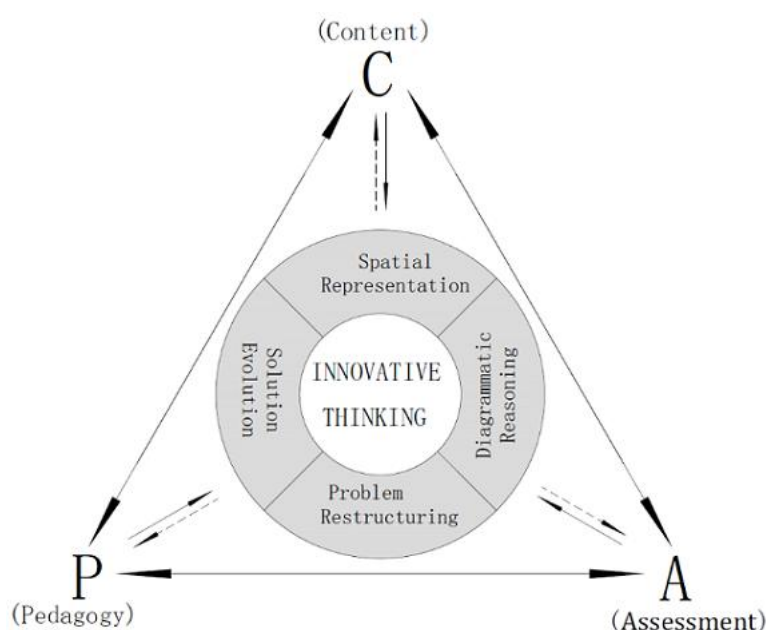


Figure 1. Overall structure of the integrated C-P-A framework for Architectural Graphics.

At the center of the system is innovative thinking, which the figure breaks down into four competencies: spatial representation, diagrammatic reasoning, problem restructuring, and solution evolution. These competencies guide content organization and, at the same time, serve as shared targets for instructional design and assessment criteria.

The arrows in the figure convey two relationships. First, content, pedagogy, and assessment are aligned toward the same four competency goals. Second, students'

task performance feeds back into the course system, influencing content updates, pedagogical choices, and adjustments to assessment weighting.

In this way, the course is no longer a static linear process—“set the content, choose the method, and then test at the end.” Instead, it becomes a dynamic system that operates and recalibrates over time around competency goals.

4.3. Design logic of core dimensions

4.3.1. Content dimension: Modular restructuring logic

This paper restructures course content into a three-part structure—knowledge, context, and tasks. Core graphics knowledge forms the base; real or near-real architectural contexts serve as carriers for that knowledge; and contextualized tasks translate competency goals into observable learning performances.

For knowledge organization, the framework retains foundational topics such as orthographic views, axonometric drawing, and drafting standards, but it repositions them as tools students can draw on when addressing spatial problems. Traditionally, projection geometry is taught as a standalone unit in a “lecture–practice–application” sequence. Here, projection principles are embedded from the outset in concrete tasks on spatial cognition, so that students use projection rules as they work through specific spatial transformation problems. In this way, foundational theory shifts from isolated content to a thinking tool used in problem solving.

For context configuration, traditional graphics teaching often uses abstract solids (e.g., cut solids and intersecting solids) as the main practice objects, because they make projection rules and representation standards easier to highlight. However, such objects lack functional relations and use scenarios. After completing the drawings, students have limited grounds to reason about spatial use or functional organization. In the proposed framework, some abstract exercises are replaced with architectural scenarios selected along a difficulty gradient, each with clear functional relations and spatial constraints. Graphics knowledge is then situated within these scenarios. This is not meant to turn a graphics course into a design studio. Rather, the context adds constraints that can be analyzed and discussed. For example, when drawing the plan of a small exhibition space, students naturally need to consider visitor circulation and functional zoning, which provides a concrete basis for diagrammatic analysis and classroom discussion.

For task generation, the framework replaces isolated drawing commands (e.g., “use orthographic views to represent the form”) with integrated graphics problems that require students to make judgments in a given context and justify them. Take a section drawing exercise as an example. A conventional task may simply ask students to “draw the section.” An integrated task instead asks them to choose a cutting position that best reveals the spatial relations of a hillside dwelling and to explain why. This links the use of graphics knowledge with the articulation of reasoning.

4.3.2. Pedagogy dimension: Combining blended and inquiry-based learning

Within the integrated Content–Pedagogy–Assessment (C-P-A) framework, pedagogy is not about lecture format. The focus is how task organization and classroom interaction can make students’ thinking visible on drawings. To avoid a single rigid mode, the framework combines blended learning with inquiry-based

learning and structures teaching in phases that follow students' development of spatial cognition.

In the early phase, instruction first targets students' ability to translate between views while keeping representations consistent. Drafting standards and basic concepts are completed online before class. Face-to-face sessions then concentrate on hands-on demonstration, timed practice, and immediate correction, with peer checking used to surface common error patterns. This helps feedback move beyond "wrong drawing" to the specific source of the mistake. The arrangement strengthens students' judgment of spatial correspondences and sharpens their sensitivity to representational accuracy.

Once basic drafting competence becomes stable, training shifts to using drawings to analyze problems. Class sessions adopt a workshop format with small-group collaboration and short tasks that focus on a single spatial logic. For example, students may use a functional zoning plan to examine zoning decisions in a healthcare setting, or use a circulation diagram to reason through internal movement organization. Through targeted questioning, the teacher prompts students to turn intuitive judgments into checkable drawing-based grounds. Students submit thinking sketches, diagrams, and records of change. These materials support classroom discussion and feedback: they allow the teacher to follow students' reasoning paths and enable peers to compare different analysis strategies.

In the final phase, single competencies are ultimately integrated and tested in more comprehensive situations. Students work on open-ended architectural tasks where they need to balance functional layout, circulation organization, and spatial scale at the same time. Drawing is no longer only a technical output; it becomes a tool for advancing solution thinking. Based on students' process evidence—such as diagrams used in solution development and written notes on design decisions—the teacher assesses students' reasoning process and provides targeted guidance, supporting the development of solution evolution capability.

4.3.3. Assessment dimension: Multiple forms of evidence and formative feedback

Within the integrated Content–Pedagogy–Assessment (C-P-A) framework, assessment is not limited to whether a drawing is "correct." The focus shifts to whether students can identify problems on the drawing, identify conflicts, justify trade-offs, and support the impact of revisions with evidence. End-of-term exams and summative drawings can check drafting standards and representational accuracy, but they rarely reveal the thinking traces behind drawing decisions. For this reason, the framework shifts assessment attention toward the learning process. Portfolios and comprehensive drawings are retained to check compliance and completeness. In addition, sketches, analysis diagrams, version comparisons, and the evolution diagrams are included as process evidence, used to examine whether students' pathway—from problem identification, to reasoning and trade-offs, to solution revision—has traceable drawing-based grounds that can be referred back to.

Formative feedback is evidence-centered and runs through the entire learning process. During in-class practice and group discussion, the teacher annotates drawings and asks for key evidence, adding brief demonstrations only when needed. At the end of each module, the teacher conducts a diagnostic review using process evidence (sketches, analysis diagrams, version comparison, and the evolution diagram), locating problems in specific steps such as reading a drawing, making labels, or building an argument, and then offering focused revision advice. Where appropriate,

peer review is added to check drawing readability. When students judge whether an axonometric drawing clearly reveals spatial hierarchies, or whether crossings in a circulation diagram are correctly marked, they have to apply their own standards for spatial representation. This act of judgment is itself an assessment of competency. When a student can accurately point out the logical flaws in a peer's diagram, it suggests that the student has formed a relatively stable evaluative frame.

4.4. Core mechanism

The C-P-A framework clarifies, at a macro level, how content, pedagogy, and assessment work together. For classroom enactment, however, a practical mechanism is needed to translate competency goals into executable teaching plans. For this purpose, this paper proposes the Indicator–Task–Evidence (I-T-E) unit as the framework's basic implementation unit.

An I-T-E unit treats a single graphics learning activity as three tightly linked elements: indicator, task, and evidence. The indicator is derived from the four innovative thinking competencies (Section 3.3), but it is not stated as a broad competency label. Instead, it is specified as an observable performance. For example, spatial representation is too general to guide teaching directly. When it is operationalized as “the student can draw a side elevation based on a plan and a front elevation,” the instructional target and what counts as achievement become explicit. The task is designed around the indicator. It is not an isolated drawing drill, but an action requirement embedded in a particular architectural context—for instance: given the plan and front elevation of a house with a gable roof of equal pitch, students are asked to draw both side elevations and explain how the roof intersection lines are formed. The evidence consists of visual outputs students produce as they complete the task, which show whether the indicator has been met—for example, the completed side elevations and the written explanation of the roof-line formation. Evidence is used not only for assessment; it also helps the teacher locate where students' understanding breaks down and adjust subsequent instruction.

In implementation, multiple I-T-E units with related competency themes form a teaching module. Modules are sequenced from lower to higher cognitive demand, together constituting the course structure for a semester. Module design and implementation are detailed in Chapter 5.

5. Instructional Design Elaboration: Operational Examples of the Framework in Architectural Graphics

5.1. Teaching context and course positioning

This chapter's instructional design elaboration is planned for first-year students and uses healthcare architectural spaces as the core teaching context. The choice of a hospital setting is based on three considerations. First, hospitals typically have relatively explicit functional zoning and circulation organization, which makes them suitable for analysis through plans, functional analysis diagrams, and circulation diagrams. This, in turn, provides a basis for training spatial transformation, circulation reading, and diagrammatic reasoning. Second, hospitals connect with students' everyday experience. This helps reduce the cognitive load of understanding the context, allowing students to focus on diagram-based expression and articulating their reasoning. Third, hospital space can be decomposed into spatial units of varying

scales, which supports task design along a difficulty gradient. It also allows competency development to progress in a spiral sequence across the semester and creates potential links to subsequent courses. It should be clarified that the “contextualized tasks” in this chapter still center on presenting problems through drawings and diagrams, generating evidence, and conducting reasoning. They are not intended to produce a complete studio-style design proposal. On this basis, the chapter uses a sequence of example contexts—“inpatient unit–outpatient circulation–nurses station”—to progressively deepen four competencies: spatial representation, diagrammatic reasoning, problem restructuring, and solution evolution. The framework’s course operation is then illustrated through a “module–I–T–E unit” organization.

5.2. Module structure and coordinated implementation

To illustrate how the framework operates across teaching phases, the Architectural Graphics course is divided into three teaching modules. The modules are organized around the four competencies of innovative thinking and are coordinated across the three framework dimensions—content, pedagogy, and assessment (see Table 1).

Table 1. Modular Coordination Logic of the Integrated C-P-A Framework in Architectural Graphics.

Core module	Innovative thinking focus	Content	Pedagogy	Assessment
Module 1: Graphics Fundamentals and Spatial Cognition	Spatial Representation	Knowledge: projection principles, orthographic views, axonometric drawing, section drawings Context: simple functional spaces (e.g., hospital inpatient rooms) Tasks: standards-based drafting and accurate representation	focused instruction and demonstration; flipped classroom; self-directed learning	standards-based rubrics; peer review; sketch-based diagnosis
Module 2: Graphic Translation and Thinking Training	Diagrammatic Reasoning; Initial Problem Restructuring	Knowledge: methods of diagrammatic analysis Context: moderately complex spaces (e.g., hospital outpatient areas) Tasks: functional and circulation analysis diagrams	design workshops; group collaboration; guided questioning	reasoning-process rubrics; problem analysis reports
Module 3: Graphics Practice and Innovative	Problem Restructuring; Solution Evolution	Knowledge: integrated drawing sets Context: complex	project-based learning; design workshops	process reflection reports; portfolios

Application		settings (e.g., nurse station) Tasks: multi-option evolution and design resolution		
-------------	--	---	--	--

5.3. Representative teaching contexts and task examples

5.3.1. Module 1 example: View representation of an inpatient room unit

This example is placed in Module 1: "Graphics Fundamentals and Spatial Cognition." The training focus is to help students build a stable mapping between two-dimensional drawings and three-dimensional space. The context is a simplified single inpatient room. Its spatial hierarchy is clear, dimensional relations are relatively fixed, and elements are few with clear relationships. This allows students to concentrate on projection rules without being distracted by complex functional interactions.

5.3.1.1. Competency indicators

The indicators in this unit are derived from spatial representation. Students are expected to translate the written requirements and functional constraints in the task brief into drawable spatial relations, and represent them through orthographic views and axonometric projection. The key is not simply producing drawings, but ensuring consistency across views. For instance, if the same door is located differently in the plan and the elevation, or if the door swing conflicts with furniture relations in another view, this often indicates that the spatial relations remain unclear. For this reason, cross-view consistency—maintaining coherent spatial correspondences between the orthographic views and the axonometric drawing, without view conflicts or errors—is therefore a key indicator in this unit.

5.3.1.2. Task design and classroom enactment

The instructor provides a simplified task brief that asks students to produce a drawing set for a single inpatient room, including a plan, orthographic views, and a wireframe axonometric drawing. The brief specifies the basic room program and approximate dimensions, and it adds two constraints: a continuous path must be maintained from the room door to the bed and to the bathroom entrance; and the door swing must not interfere with furniture. These constraints require students to consider the logic of spatial use before drafting, rather than mechanically "placing" elements.

Students begin with a schematic sketch of the layout. Linework standards are not required at this stage, but the sketch must show the relative positions of openings, the bed, and the bathroom, and it must mark the main circulation path. During walkthroughs, the instructor asks targeted questions, and students gradually translate spatial judgments into explicit drawing marks as they respond. The task brief also leaves some dimensions open. For example, students determine the bathroom door width based on wheelchair access and note their rationale on the drawing. After the sketch is checked, students refine it into a formal plan layout.

Students then complete the orthographic views. Matching reference numbers are placed at key points (e.g., door opening corners and window-sill endpoints) so that the same component can be traced across drawings. In the wireframe axonometric

drawing, students mark reference lines—such as sill lines and opening edges—and use them as references to compare elevation data in the plan with spatial positions shown in the axonometric view.

Peer checking is also built into the class session. Using a checklist, students review each other's drawings item by item, with attention to locations where cross-view inconsistency commonly occurs, such as door/window positions and furniture elevations. When problems are found, students correct them on the spot and record the issue and correction in the corner of the sheet.

5.3.1.3. Evidence collection and feedback

Evidence in this unit primarily comes from students' submitted drawings and aligns with the two teaching phases.

In phase 1, students submit the plan with key dimensions and a brief rationale. Assessment checks whether the spatial relations among the entry, circulation path, bed position, and bathroom are workable, whether the door swing conflicts with furniture, and how students mark and resolve such conflicts.

In phase 2, students submit the orthographic views and the wireframe axonometric drawing. The orthographic set includes matching reference numbers and leaders. Assessment focuses on whether door/window openings, partition corners, and bed locations remain consistent across views. The axonometric drawing is assessed together with the verification record, with attention to whether the marked reference lines were actually used to compare against the orthographic set, and whether the record shows a concrete checking path.

Common errors collected during walkthroughs and grading—for example, inverted occlusion relationships or inconsistent window locations across drawings—can be saved for a whole-class debrief.

5.3.2. Module 2 example: Outpatient circulation analysis and diagram-based optimization

This example is placed in Module 2: "Graphics Translation and Thinking Training". The training focus shifts to diagrammatic reasoning and begins to address problem restructuring. The context moves from a single inpatient room to a hospital outpatient floor, where students no longer work with an isolated room but with a system in which multiple user groups move and intersect on the same plan.

5.3.2.1. Competency indicators

The indicators in this unit are sequenced from basic to advanced in the order that reasoning typically unfolds in class. Students first need to produce a functional zoning plan and a circulation diagram, clearly marking three user groups—patients, clinical staff, and logistics/support staff—while marking origins/destinations and key nodes. Building on this, students identify problems on the diagram and explain why conflicts occur. Examples include three routes converging at the same point, a corridor encroached upon by overflow from a waiting area, or queues at service counters creating recirculation. Finally, students propose an adjustment strategy, draw at least one specific adjustment, and use a before–after comparison diagram to show how circulation patterns shift.

5.3.2.2. Task design and classroom enactment

The instructor provides an outpatient plan with built-in flaws. Key nodes (e.g., entrance, lobby, registration, waiting area, consultation rooms, and payment) are pre-marked. Working in groups, students use diagrammatic analysis to identify problems and propose adjustments.

At the start of the task, each group delineates key boundaries that shape circulation and prepares a functional zoning base map. They then draw three circulation routes (patients, clinical staff, and logistics/support staff) and conduct a circulation overlay on a single sheet to examine their relations. On the overlaid diagram, students mark crossings, congestion, and recirculation nodes, and add short notes to specify the conflicting elements, the cause, and the conditions under which the conflict arises.

In the final step, each group proposes an adjustment. At least one change must be specific and locatable. Using a side-by-side before–after comparison diagram, students explain what was changed, why the change was made, and how circulation patterns will shift as a result.

5.3.2.3. Evidence collection and feedback

Evidence in this unit comes from students' submitted drawings. For the functional zoning plan and the circulation overlay, assessment checks whether zoning boundaries are clear, whether the three circulation routes are distinguishable, and whether crossings and bottlenecks can be identified directly on the drawing. For the marked problem nodes and accompanying notes, assessment focuses on whether students can capture the core contradiction and explain where the problem is, who is primarily affected, and why it occurs. For the side-by-side before–after comparison, assessment examines whether revisions respond to previously identified problems and whether the adjustment logic remains internally consistent. Group discussion notes and draft sketches can be used as supplementary evidence to show how groups revised their judgments and reached consensus.

Feedback relies primarily on in-class discussion and a whole-class review. During class, the instructor provides immediate feedback through annotated comments and targeted questions. At the end of the unit, two or three representative group submissions are selected for comparative analysis with the whole class, so that the trial-and-error experience of individual groups can be translated into reusable reference points for spatial judgment.

5.3.3. Module 3 example: Multi-option generation and evolution for a nurse station

This example is placed in Module 3: “Graphics Practice and Innovative Application”. It asks students to integrate spatial representation and diagrammatic analysis in a complete context while developing problem restructuring and solution evolution. The task uses a small nurse station as the setting. Although the scale is limited, it carries built-in tensions: nurses need efficient visibility and patrol access to patient-room doors, while patient privacy must be protected. Space is also needed for family waiting, supply movement, and staff circulation. In such a compact area, these demands cannot all be optimized at once. Students therefore need to weigh trade-offs, make choices, and leave the rationale on drawings and in their process records.

5.3.3.1. Competency indicators

This unit has no standard answer. Indicators therefore should not be set around correctness. They are defined around three key performances that emerge during solution generation.

(a) Problem restructuring and externalization. Students should be able to break down the core tension through diagrams and make it visible on the drawing. For example, they should show where visibility coverage conflicts with privacy protection, and which segments of circulation are encroached on by family waiting.

(b) Multi-option generation. Students should be able to propose several clearly distinct layout options for the same tension and identify the strengths and weaknesses of each. For instance, one option may maximize nurse visibility but weaken patient privacy; another may shorten patrol routes but place the station in a suboptimal location.

(c) Solution evolution and trade-offs. Students should use an evolution diagram to show how a proposal changes from an initial draft to a final version, and explain the rationale for each key change. For example, relocating the station may improve visibility but create privacy exposure, which then needs to be compensated for through partitions.

5.3.3.2. Task design and classroom enactment

The instructor provides a simplified plan of a nursing unit. It marks patient-room distribution, corridor alignment, and the approximate zone for the nurse station, and it states core constraints: ensure effective visibility to patient-room doors to improve patrol efficiency, while also addressing privacy and allowing space for family waiting. Compared with the previous two examples, this unit is closer to a small project.

The class works in groups. Before generating layout options, each group uses diagrams to surface the key issues. On the plan, they draw a line-of-sight diagram and a path diagram, mark visibility blind spots, detour segments, and potential exposure points, and add short notes to explain the grounds for these judgments.

Once problems are identified on the drawings, groups move to multi-option generation. They propose at least four clearly different layout options, presented through sketches with visibility and circulation annotations. They then select one option as a baseline and run two to three rounds of revision. An evolution diagram is used to simultaneously record what was changed, why the change was made, and what downstream effects it produced. Each group also submits a 200–300 word reflection aligned with the evolution steps.

5.3.3.3. Evidence collection and feedback

Evidence in this unit is mainly drawn from students' drawings. It includes problem-restructuring diagrams, multi-option sketches, and evolution diagrams. Problem-restructuring diagrams (e.g., the line-of-sight diagram and path diagram) are used to judge whether students can represent the core tension and key constraints clearly in graphic form. Multi-option sketches are used to check whether options differ in substantive ways rather than through minor detailing. Evolution diagrams are used to examine whether the evolution pathway from draft to final is traceable, and whether trade-off rationales are visible on the drawings. The written reflection serves as supplementary evidence. It is read alongside the evolution record to judge whether students explain their trade-offs clearly.

Feedback is organized mainly through an open pin-up review. The instructor selects evolution diagrams from several groups for peer critique, focusing on whether revisions address earlier identified tensions and whether the trade-offs remain internally consistent. By comparing peers' reasoning, students are guided to recalibrate their own judgment standards.

6. Discussion

6.1. Theoretical contributions

This paper addresses a central issue: Architectural Graphics can move beyond a tool-oriented course centered on standards and drawing correctness, and become a learning platform that supports thinking through graphic operations. Prior work suggests that drawings can participate in the thinking process, yet these insights have rarely been translated into course-level design. This paper repositions Architectural Graphics as a learning platform in which drawings are used not only to present outcomes, but also as cognitive tools. They support students in externalizing ideas into graphical forms and in refining those ideas through repeated externalization, inspection, and revision.

To enact this positioning in teaching, innovative thinking in graphics classes needs to be defined as competency goals that can be organized through instruction and checked through assessment, rather than left as an abstract ideal. Accordingly, the paper specifies four competencies—spatial representation, diagrammatic reasoning, problem restructuring, and solution evolution—and links them to typical classroom tasks such as multi-view translation, functional and circulation diagramming, problem redefinition within tasks, and version-based comparison of solution options. This mapping yields a conceptual framework that can be used directly for course design.

A competency framework alone does not explain how a course can operate continuously. A course mechanism is still needed to connect goals, learning activities, and assessment. This paper draws on Biggs' constructive alignment. However, in Architectural Graphics, creative thinking is difficult to judge through summative drawings alone. The same drawing task can also point to different competency goals under different instructional intentions, which makes direct transfer of the alignment principle problematic. To address this, an integrated Content–Pedagogy–Assessment (C-P-A) framework is proposed. The framework operationalizes teaching activities through the Indicator–Task–Evidence (I-T-E) unit, creating a classroom cycle of indicator–task–evidence.

6.2. Implications for teaching practice

From the teaching practice perspective, the paper highlights a regularity in classroom operation revealed by the framework: when the same drawing formats are placed within different task structures, the learning activity students actually engage in can change substantially. Across the three contexts in this study, the inpatient room unit uses orthographic views and axonometric drawings to develop students' ability to map and translate between two-dimensional and three-dimensional relations. The outpatient circulation task, in contrast, treats the plan as an analytic tool for identifying congestion and conflicts and for making judgment grounds explicit. The nurse station task goes one step further by requiring students to set comparison criteria, make trade-offs across multiple versions, and explain their choices through diagrams. These contrasts suggest that course reform does not hinge on replacing content or

adding new technologies. It hinges on task redesign so that established graphics tools can serve richer cognitive functions.

Shifts in assessment can also shape students' learning strategies. When assessment mainly checks whether drawings meet standards, students tend to pursue a single "correct" answer. When assessment instead attends to process evidence and ongoing feedback, students are more likely to preserve revision traces, document discarded versions, and articulate trade-off rationales in reflection. In this way, innovative thinking does not rely on repeated verbal reminders from the instructor. It is built into the task structure and assessment mechanism as part of the course's normal operation.

6.3. Implementation challenges and strategies

Turning the framework from an abstract idea into classroom practice raises several practical issues. The most immediate constraint is instructional time. Architectural Graphics already carries a heavy content load and a high skills threshold. Under fixed contact hours, adding thinking-oriented tasks can exceed what the schedule can support. This paper does not argue for increasing course hours. Instead, it stresses reorganizing how existing time is used: time previously spent on repeated explanation-and-drill of basic techniques can be released, so that technique practice is completed in parallel with solving concrete spatial problems. This shift also places new demands on instructors who are accustomed to a "lecture first, practice later" routine, and it therefore calls for accompanying supports and example templates.

Another challenge is assessment expertise. The framework expects instructors to recognize traces of reasoning in students' drawings, judge the adequacy of the evidence, and provide process-oriented feedback accordingly. Compared with correctness-based marking, this requires stronger diagnostic judgment and feedback skills. A practical response is to provide structured assessment tools—standardized rubrics and evidence checklists—so that feedback is anchored in explicit criteria and less dependent on individual experience.

Student heterogeneity is also an important concern. First-year cohorts often differ widely in spatial representation and graphic reasoning, while the framework's modular progression assumes that students can keep pace. To avoid widening gaps over time, implementation should include additional support for students with weaker foundations. Other practical conditions also shape feasibility: some students may lack intuitive experience with hospital spaces; instructors vary in their experience with running workshops and peer review; and institutional resource constraints in equipment and tools can affect implementation efficiency.

Given these constraints, a cautious approach is to pilot one to two I-T-E units first. For example, the Module 1 inpatient room task can replace one teaching week of abstract solid exercises, and the decision to extend into later modules can be made based on observed effects. At the same time, institutions should be allowed to adjust contexts, task difficulty, and assessment weighting without altering the core mechanism, so as to improve feasibility and sustainability.

7. Conclusions

Reform in Architectural Graphics does not hinge on adding new content or adopting new tools, but focuses on redesigning tasks and assessment so that students produce—and preserve—a traceable record of their thinking through graphic operations. This paper proposes an integrated Content–Pedagogy–Assessment (C-P-A) framework and

illustrates its operational design through a three-module instructional design elaboration situated in hospital-space contexts. The elaboration suggests that competency goals can be activated through tasks, and that student work can yield evidence that supports judgment and feedback.

It should be noted that the elaboration is built on the framework logic and teaching experience. It can show internal coherence, but it cannot guarantee effective operation once implemented in real classrooms. A major limitation of the current study is the lack of classroom-based empirical data. What cognitive performances will students actually show when working on these tasks? Will the four competencies develop in the intended sequence? What unanticipated barriers will instructors face during implementation? These questions require verification through classroom evidence. Future work therefore needs small-scale pilots in authentic settings: selecting one to two Indicator–Task–Evidence (I-T-E) units, implementing them across two course iterations, and tracking competency development through pre/post comparisons and process records.

Beyond piloting, whether the framework can be scaled will ultimately depend on the practicality of assessment. Further work is needed to develop structured tools that can capture change in the four competencies—spatial representation, diagrammatic reasoning, problem restructuring, and solution evolution—including standardized rubrics, peer-review guidelines, and a portfolio assessment scoring framework. These tools are necessary to strengthen the validity, reliability, and fairness of assessment results.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Funding

This research was funded by the Hubei Provincial Department of Education (China), Provincial Teaching Reform Research Project for Higher Education Institutions (2022), grant number 2022025.

References

- [1] Pan, Y.; Zhang, L. Roles of artificial intelligence in construction engineering and management: A critical review and future trends. *Autom. Constr.* 2021, 122, 103517, DOI: 10.1016/j.autcon.2020.103517.
- [2] Casakin, H.; Wodehouse, A. A systematic review of design creativity in the architectural design studio. *Buildings* 2021, 11(1), 31, DOI:10.3390/buildings11010031.
- [3] Jia, L.; Yang, Q. Research and practice on teaching reform of engineering architectural drawing course. *J. Anhui Univ. Technol. (Soc. Sci.)*, 2022, 39, 71-72, 102, DOI: 10.3969/j.issn.1671-9247.2022.06.018.
- [4] Lu, J.; Zhang, Y.; Chi, J. Flipped classroom practice in engineering graphics: Taking ‘drawing methods of composite solids’ as an example. *J. Capital. Norm. Univ. (Nat. Sci. Ed.)*, 2021, 42(6), 64-70, DOI: 10.19789/j.1004-9398.2021.06.011.

- [5] Martín Erro, A.; Martínez Muneta, M.L.; Rodríguez Sevillano, Á.A. Exploring freehand drawing skills of engineering students as a support of visualization. *Educ. Sci.* 2024, 14, 641, DOI: 10.3390/educsci14060641.
- [6] Avotiņa, A.; Karlsons, I.; Urdziņa-Deruma, M.; Celmiņa-Ķeirāne, A. Sketching as an external representation of thinking results and processes in education. *Draw. Res. Theory Pract.* 2023, 8, 295-310, DOI: 10.1386/drtpr_00122_1.
- [7] Wang, Y.; Du, X.; Yang, R.; Zhu, J.; Cao, X. A new blended teaching system for engineering graphics based on OBE. *J. Graph.* 2021, 42(4), 696-702, DOI: 10.11996/JG.j.2095-302X.2021040696.
Available online: <http://www.txxb.com.cn/CN/10.11996/JG.j.2095-302X.2021040696> (accessed on 24 February 2026).
- [8] Geng, J.; Li, Y.; Ran, Y.; Zhou, Z. Research on engineering drawing teaching reform based on OBE-CDIO concept. *Creat. Educ. Stud.* 2025, 13, 287-291, DOI: 10.12677/ces.2025.135338.
- [9] Biggs, J.B.; Tang, C. *Teaching for Quality Learning at University: What the Student Does*, 4th ed.; Open University Press: Maidenhead, UK, 2011; ISBN 9780335242757.
- [10] Loughlin, C.; Lygo-Baker, S.; Lindberg-Sand, Å. Reclaiming constructive alignment. *Eur. J. High. Educ.* 2021, 11(2), 119-136, DOI: 10.1080/21568235.2020.1816197.
- [11] Novica, D.R.; Wianto, E.; Andrade Campos, S. Drawing and ideation process in design education: A systematic literature review. *Cogent Arts Humanit.* 2023, 10(1), 2219487, DOI: 10.1080/23311983.2023.2219487.
- [12] Do, E.Y.-L.; Gross, M.D. Thinking with diagrams in architectural design. *Artif. Intell. Rev.* 2001, 15, 135-149, DOI: 10.1023/A:1006661524497.
- [13] Brosens, L.; Raes, A.; Octavia, J.R.; Emmanouil, M. How future proof is design education? A systematic review. *Int. J. Technol. Des. Educ.* 2023, 33(2), 663-683, DOI: 10.1007/s10798-022-09743-4.
- [14] Wang, H.; Ma, X.; Sun, X. Course construction and reform of engineering graphics based on OBE. *Gaojiaoxuekan* 2022, 22, 67-70, 74, DOI: 10.19980/j.CN23-1593/G4.2022.22.016.
Available online: <https://www.chndoi.org/Resolution/Handler?doi=10.19980/j.CN23-1593/G4.2022.22.016> (accessed on 24 February 2026).
- [15] Mei, S.; Song, Y.; Wang, X.; Zhou, Q.; Zhang, H. Review and analysis of BIM curriculum setting issues in general universities. *Higher Archit. Educ.* 2020, 29(5), 167-177, DOI: 10.11835/j.issn.1005-2909.2020.05.023.
Available online: <http://gdjzjy.com.cn/thesisDetails#10.11835/j.issn.1005-2909.2020.05.023&lang=zh> (accessed on 24 February 2026).
- [16] Guan, H.; Xu, J.; Gong, C.; Gao, L. Application of virtual reality in architectural spatial cognition. *Higher Archit. Educ.* 2020, 29(5), 156-166, DOI: 10.11835/j.issn.1005-2909.2020.05.022.
Available online: <http://gdjzjy.com.cn/thesisDetails#10.11835/j.issn.1005-2909.2020.05.022&lang=zh> (accessed on 24 February 2026).
- [17] Ruan, C.; Huang, Q.; Huang, J.; Zhang, L.; Li, X. Constructional design and practice of blended learning mode for engineering graphics course based on

- information technology. *J. Graph.* 2016, 37, 846-850, DOI: 10.11996/JG.j.2095-302X.2016060846.
- [18] Onsmán, A. Assessing creativity in a 'New Generation' architecture degree. *Think. Skills Creat.* 2016, 19, 210-218, DOI: 10.1016/j.tsc.2015.07.001.
- [19] Schön, D.A. *The Reflective Practitioner: How Professionals Think in Action*; Basic Books: New York, NY, USA, 1983; ISBN 9780465068784.
- [20] Goldschmidt, G. The dialectics of sketching. *Creat. Res. J.* 1991, 4, 123-143, DOI: 10.1080/10400419109534381.
- [21] Razzouk, R.; Shute, V. What is design thinking and why is it important? *Rev. Educ. Res.* 2012, 82, 330–348, DOI: 10.3102/0034654312457429.
- [22] Oo, T.Z.; Kadyirov, T.; Kadyjrova, L.; Józsa, K. Design-based learning in higher education: Its effects on students' motivation, creativity and design skills. *Think. Skills Creat.* 2024, 53, 101621, DOI: 10.1016/j.tsc.2024.101621.



© 2026 by the author(s); licensee International Technology and Science Publications (ITS), this work for open access publication is under the Creative Commons Attribution International License (CC BY 4.0). (<http://creativecommons.org/licenses/by/4.0/>)