

# Research on Teaching Reform of “Introduction to Civil Engineering” through Bidirectional Integration of Generative AI and Problem-Based Learning

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**Abstract:** Under the “Smart+” education initiative, the traditional Introduction to Civil Engineering course faces challenges such as abstract knowledge delivery and disconnection from practical applications. Guided by the core concept of “bidirectional integration,” this research systematically develops a novel teaching model that deeply incorporates generative artificial intelligence (AI) with project-based learning (PBL). This model not only employs generative AI as an intelligent tool to empower the entire PBL process but also uses authentic PBL project tasks to drive students’ high-order and critical use of AI, aiming to simultaneously enhance students’ engineering cognition and AI literacy. Teaching practice demonstrates that this model effectively stimulates students’ learning interest and improves their comprehensive ability to solve complex engineering problems, providing an actionable pathway and reference for the intelligent teaching reform of similar courses.

**Keywords:** Generative artificial intelligence; Project-based learning; Teaching reform; Bidirectional integration

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## 1. Introduction

With the advent of the “Smart+” era, artificial intelligence is driving a profound digital and intelligent transformation in the civil engineering industry, placing higher demands on practitioners’ digital-intelligent literacy<sup>[1]</sup>. However, the traditional teaching mode of the Introduction to Civil Engineering course—a crucial gateway to the profession—faces significant challenges: its content is often disconnected from cutting-edge practice, and its one-way knowledge delivery fails to stimulate students’ interest and innovative potential, underscoring an urgent need for reform. The rise of generative artificial intelligence (GenAI), represented by large language models, offers new tools to address these pedagogical difficulties. Studies show that GenAI can be effectively integrated with project-based learning (PBL); its powerful generative and conversational

capabilities allow it to serve as an “intelligent tutor,” effectively supporting project ideation, resource acquisition, and process feedback in PBL [2]. Meanwhile, the authentic, complex scenarios provided by PBL create an ideal environment for cultivating students’ critical and creative use of GenAI tools [3]. In the field of civil engineering education, initial explorations have begun to focus on the application of GenAI in supporting the teaching of specific skills [4].

Nevertheless, existing research predominantly concentrates on the instrumental and one-way application of GenAI. For foundational professional courses such as Introduction to Civil Engineering, how to systematically construct a teaching model that enables bidirectional integration and deep embedding of GenAI and PBL—shifting from mere “tool application” to “model reinvention”—remains underexplored. The proposed “bidirectional integration” aims to build an organically synergistic teaching ecosystem: GenAI enhances the quality and efficiency of the entire PBL process, while PBL drives the advanced and critical application of GenAI.

Based on this, using the Introduction to Civil Engineering course as a vehicle, this study aims to develop and validate a teaching model of “bidirectional integration of generative AI and PBL.” The paper will systematically elaborate on its design framework and implementation pathways, and through PBL teaching cases and effect evaluation, provide an actionable, practical paradigm for related instructional reform.

## **2. Definition of core concepts and the teaching philosophy of “bidirectional integration”**

### **2.1. Definition of concepts**

The core of this teaching model lies in the integration of Generative AI and PBL. Generative AI is positioned as a “project collaborator” and “intelligent tutor,” driving a transformation in the teaching structure from a teacher–student dyad to a teacher–student–machine triad [5]. Its core value as a cognitive tool is to provide knowledge retrieval, solution inspiration, writing assistance, and simulation evaluation throughout the entire project cycle. This reduces the cognitive difficulty of engineering tasks, allowing students to focus on higher-order thinking and thereby enhancing learning efficiency and depth [6]. The PBL model adopted in this study is driven by authentic, ill-structured engineering problems. Its core elements include: authentic problem-driven learning (to stimulate intrinsic motivation), sustained inquiry and product orientation (requiring completion of a full project cycle with tangible outcomes), and collaborative inquiry with assessment guidance (emphasizing teamwork and process evaluation) [7]. This process promotes students’ autonomous integration of multidisciplinary knowledge and systematically develops their higher-order abilities in solving complex problems and collaboration.

### **2.2. Core philosophy of “bidirectional integration”**

The philosophy of “bidirectional integration” aims to transcend the linear thinking of mere tool assistance, constructing a teaching ecosystem where GenAI and PBL are deeply embedded and synergistically enhance each other [8]. Its core philosophy manifests in two dimensions: first, AI-empowered PBL, which leverages generative AI to improve the implementation efficiency and situational authenticity of PBL. AI can be embedded throughout the entire “project initiation-inquiry-implementation-outcome-evaluation” cycle, assisting in problem refinement, providing learning scaffolding, supporting solution iteration, and facilitating outcome review. This makes it feasible to conduct complex, authentic projects within limited class hours. Second, PBL-empowered AI literacy, where the authentic and complex context of PBL provides a high-level arena for cultivating students’ responsible and critical AI literacy. Students must critically verify and revise AI-generated

content, and learn “prompt engineering” to precisely define problems for the AI. This process deeply hones their abilities in information discernment, critical thinking, and the responsible use of AI.

### **3. Systematic construction and implementation pathway of the “bidirectional integration” teaching model**

This section aims to systematically elaborate on the specific construction method and phased implementation pathway of the teaching model of “Bidirectional Integration of Generative AI and PBL.” Guided at the top level by the philosophy of outcome-based education (OBE)<sup>[9]</sup> and centered on the core principles of “teacher-student-machine” triadic collaboration and the integration of “teaching-learning-assessment”<sup>[10]</sup>, the model constructs a closed-loop teaching process spanning pre-class, in-class, and post-class stages. Its objective is to deeply and organically integrate intelligent technology into the entire project-based teaching cycle of the Introduction to Civil Engineering course.

#### **3.1. Overall design framework: Integrated reconstruction of “objectives-process-assessment” based on the OBE philosophy**

This model is grounded in the philosophy of OBE and adheres to the principle of “backward design.” It first defines new learning outcomes for the intelligent era, adding two core competency objectives beyond traditional goals: “AI Tool Application Competency” and “Engineering Ethics Awareness in the Intelligent Era,” ensuring alignment with future professional demands<sup>[11]</sup>. Building on this, it promotes the transformation of roles for teachers, students, and generative AI into “Learning Designer/Facilitator,” “Active Inquirer/Human-Machine Collaborator,” and “Cognitive Collaborator/Intelligent Tutor,” respectively. Ultimately, an integrated framework centered on an “Intelligent Assessment Feedback” quality loop is constructed. This framework utilizes technology to enable real-time analysis of learning process data and diversified, precise assessment, thereby allowing for the dynamic optimization of instruction and ensuring the attainment of learning outcomes.

#### **3.2. Three-phase implementation pathway: Full-cycle embedding and deep interaction of generative AI**

##### **3.2.1. Pre-class phase: AI-assisted project preparation and personalized activation**

This phase leverages generative AI to lower the barrier to project initiation, enabling efficient preview and personalized preparation<sup>[12]</sup>. Teachers use AI to quickly generate diverse project backgrounds and resource packages closely aligned with current hotspots in civil engineering, significantly enhancing lesson preparation efficiency. Students, meanwhile, utilize AI to construct a knowledge framework and initiate project ideation—for instance, by asking about “common types of road distress” or instructing the AI to “generate a research outline on sustainable building materials.” This process helps students develop a personalized “question list” while initially mastering the skill of collaborating with AI for information retrieval and integration, thereby preparing them for in-depth classroom inquiry.

##### **3.2.2. In-class phase: Human-AI collaborative inquiry and deep discussion**

The classroom transforms into a “project workshop,” with generative AI embedded into group collaboration as an “intelligent teaching assistant” or “domain expert.” Students can pose real-time questions to the AI regarding specific technical challenges, obtaining immediate feedback and alternative solutions, thus overcoming the bottleneck of delayed feedback inherent in traditional teaching. The teacher’s role deepens into that of a

facilitator, focusing on guiding students to design precise “prompts” for obtaining high-quality AI responses<sup>[13]</sup>, organizing students to compare, question, and validate the rationality and limitations of AI-generated solutions, and chairing review sessions to guide peer evaluation. The core objective is to cultivate students’ ability to engage in critical dialogue and collaborative decision-making with AI, thereby promoting the internalization and reconstruction of knowledge.

### **3.2.3. Post-class phase: Project iteration and competency extension based on AI feedback**

This phase focuses on project deepening and competency transfer. Students use generative AI to optimize the grammar, logic, and formatting of their reports and may attempt to convert design descriptions into preliminary drawings or visualization models. Furthermore, students can ask the AI to role-play as a “demanding client” or “senior reviewer,” challenging their design proposals and offering improvement suggestions, which drives multiple rounds of reflection and iteration. Teachers, on the other hand, analyze the “student-AI interaction logs” recorded by the platform to gain insights into students’ thinking processes, common difficulties, and differences in AI usage strategies. Based on this digital-intelligent evidence, teachers can provide precise, personalized guidance and use it to optimize subsequent teaching, forming a quality closed loop of “assessment–diagnosis–optimization.”

## **4. Teaching practice case**

To align with the knowledge level of first-year students and stimulate their intuitive interest in civil engineering, this study designed a teaching case centered on “Observation of Campus Road Distress and Preliminary Exploration of Maintenance Solutions.” This project guides students to focus on engineering entities in their immediate surroundings, transforming abstract civil engineering concepts into concrete tasks of observation, documentation, and analysis. It aims to cultivate their engineering sensitivity, systematic thinking, and preliminary ability to use intelligent tools to solve practical problems.

### **4.1. Project implementation process design**

This project spans three weeks, with generative AI embedded as an “intelligent collaborator” throughout all stages to support students in completing a full practice cycle from observation to preliminary design.

In the first week, the focus is on distress identification and information collection. Each group selects a campus road section exhibiting distress for on-site investigation. Here, AI serves as a “professional consultant” and “documentation assistant.” Students upload photos to a multimodal AI tool to obtain analysis of damage types and causes, quickly building a cognitive framework, while AI also aids in designing standardized survey forms to ensure comprehensive data collection.

During the second week, the emphasis shifts to cause analysis and solution ideation through AI-assisted inquiry. Groups consolidate field records and instruct the AI to analyze specific phenomena and suggest countermeasures. The teacher guides students to critically evaluate the applicability, economic viability, and social impact of the AI-proposed solutions, enabling them to weigh engineering options within a practical context.

In the final week, activities center on report writing and deliverable refinement, with AI acting as a “writing coach” and “design assistant.” Students instruct the AI to help organize findings into structured reports and polish presentation materials. Crucially, students must verify, revise, and rework all AI-generated content to ensure the final deliverables authentically reflect the group’s own observations and critical thinking.

## 4.2. Student deliverables and focus of instructional assessment

The final deliverables for this case consist of a distress investigation report and a presentation deck (e.g., PPT). The report should cover detailed descriptions of the distress (with supporting photos and sketches), cause analysis, a comparison of alternative maintenance solutions, and final recommendations. Assessment employs a diversified approach, focusing particularly on the depth of AI tool application, the demonstration of preliminary critical thinking, engineering mindset, and systemic analysis skills, as well as teamwork and professional communication abilities.

## 5. Conclusion

This study constructed and implemented a teaching model of “Bidirectional Integration of Generative AI and PBL,” providing a concrete pathway and an empirical case for reforming introductory civil engineering courses in the intelligent era. Preliminary analysis indicates that the model is highly effective in stimulating students’ inquiry interest, enhancing project quality, and fostering AI literacy. Crucially, it facilitates a shift in students’ perception—generative AI transitions from being viewed as an “entertainment tool” to a “production tool” and “collaborative partner” in professional learning. This demonstrates that the “bidirectional integration” philosophy effectively unites technological empowerment with literacy development objectives, offering a viable path for cultivating future engineers capable of leveraging intelligent tools to solve complex engineering problems.

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## Disclosure statement

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