Generative AI in STEM Projects to Develop Analytical Thinking and Problem-Solving

Thaweesin Amnuaiphanwilai, Naresuan University, Thailand
Wanchalearm Junsong, Naresuan University, Thailand

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Abstract

This research investigated the integration of Generative AI (GenAI) in STEM project-based learning for 22 9th-grade students. The study aimed to develop usage guidelines, measure effects on analytical thinking and problem-solving, and create an instructional model. Findings revealed that all students (100%) used GenAI for project development, reporting high satisfaction (4.67 average) due to its ease of use. GenAI assisted in all project stages—from problem analysis to presentation—by aiding information retrieval, design, coding, and complex problem-solving. A key limitation identified by students was the need to verify GenAI's information for accuracy. The study confirmed GenAI's positive impact: students' post-instruction analytical thinking and problem-solving skills were significantly higher than pre-instruction (at the .05 statistical level). Furthermore, a five-stage instructional model (problem identification, planning, execution, artifact creation, presentation) using GenAI as a supporting tool was developed. Experts evaluated this model, which targets analytical skills and teamwork, as highly appropriate (4.36 average).

Keywords: STEM, generative AI, analytical thinking and problem-solving skills

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Introduction

In the landscape of 21st-century education, cultivating higher-order cognitive competencies—such as analytical thinking, complex problem-solving, collaborative teamwork, and digital literacy—has become the cornerstone of modern educational reform (Partnership for 21st Century Skills, 2019). This shift is particularly crucial within Science, Technology, Engineering, and Mathematics (STEM) disciplines, which drive national innovation, socio-economic development, and readiness for a digitized global economy. Project-Based Learning (PBL) is widely recognized as one of the most effective pedagogical strategies for STEM instruction (Krajcik & Blumenfeld, 2006). By centering learning on authentic, real-world problems, PBL encourages students to actively synthesize theoretical concepts across diverse subject matters, design tangible prototypes, and evaluate practical outcomes (Barron & Darling-Hammond, 2008).

Despite its theoretical benefits, the classroom execution of STEM-focused PBL presents significant instructional hurdles (Blumenfeld et al., 1991). Secondary students, particularly 9th-graders, frequently struggle with cognitive overload when navigating multi-disciplinary requirements. For instance, developing a smart agricultural device requires a simultaneous understanding of biological parameters (Science), microcontrollers and wiring (Technology), structural prototyping (Engineering), and raw data calculations (Mathematics). Without immediate, highly personalized scaffolding, students often experience frustration during complex data analysis, syntax debugging in coding, or structural design iterations. These obstacles can stall project progression and diminish student motivation.

Concurrently, the rapid emergence of Generative Artificial Intelligence (GenAI) tools—such as ChatGPT, Google Gemini, and AI-driven graphic engines—offers a transformative approach to scaffolding student learning. GenAI[1] functions not merely as a passive search engine, but as an active, dialogic cognitive assistant capable of generating customized computer code, analyzing unstructured qualitative data, modeling engineering designs, and suggesting immediate troubleshooting methods. Integrating GenAI as a supporting tool within STEM projects could mitigate students' operational bottlenecks, allowing them to allocate more cognitive resources toward critical analysis and creative problem-solving.

However, the educational adoption of GenAI remains largely unstructured, raising concerns regarding plagiarism, critical thinking suppression, and an over-reliance on automated answers. In the context of Thailand’s educational system, integrating AI into secondary-level STEM workflows is a novel frontier requiring empirical investigation and rigorous pedagogical guidelines. This research seeks to address this gap by establishing an evidence-based framework.

The primary objectives of this study are:

1. To study and establish operational guidelines for utilizing Generative AI within the secondary STEM project-based learning process.
2. To investigate the empirical effects of GenAI integration on the development of students' analytical thinking and problem-solving skills.
3. To design, evaluate, and validate a comprehensive instructional management model that seamlessly blends GenAI workflows with STEM project execution.

Literature Review

Generative AI in Modern Educational Settings

Generative AI refers to advanced machine learning models (primarily Large Language Models or LLMs) trained on massive datasets to generate novel text, computer code, images, and other media based on user-inputted natural language queries (prompts) (Brown et al., 2020). In educational research, GenAI is recognized for its ability to act as a customized, on-demand tutor that adapts to an individual student's pacing and learning style (OpenAI, 2023). According to Majumdar and Gupta (2024), GenAI can provide localized explanations of abstract scientific concepts, translate technical documentation, and write functional starter scripts for microcontrollers. However, the pedagogical challenge lies in maintaining a balance between automated scaffolding and active student critical inquiry (Lee et al., 2025).

Project-Based Learning (PBL) and STEM Integration

PBL is an instructional method that engages students in deep, continuous investigation of complex, meaningful questions (Guido, 2024). In STEM education, PBL serves as a unifying framework where science provides the theoretical understanding, mathematics provides the analytical precision, engineering offers the structural problem-solving methodology, and technology acts as the enabling tool (Klomim, 2016). Traditional models of PBL follow highly structured sequences, such as 7-stage or 9-stage workflows. However, when integrating digital technologies like AI, these stages must be re-evaluated to prevent technological tools from overshadowing the learning objectives (Xiao & Li, 2023).

Cognitive Tools and Critical Thinking

A “cognitive tool” is a technological device or environment that helps learners perform cognitive operations that would otherwise be difficult or impossible (Jonassen, 2000). According to cognitive load theory, by offloading routine mechanical tasks (such as searching through manual libraries or fixing basic coding syntax errors), students can focus their working memory on higher-level analytical tasks (Zhao et al., 2025). Recent research indicates that GenAI can act as a highly effective cognitive tool. For example, in computer science and STEM education, AI-assisted feedback loops help students self-correct coding errors in real-time, boosting their self-efficacy (Chen et al., 2024).

However, studies also caution against “unverified trust” in AI outputs. In studies involving knowledge workers and students, Lee et al. (2025) and Katarzyna Szmyd & Ewelina Mitera (2024) observed that over-reliance on AI can lead to a decline in independent critical thinking. Therefore, pedagogical frameworks must explicitly include steps for data verification, prompting, and critical evaluation (Girish, 2025; Ruiz Viruel et al., 2025).

Methodology

The study utilized a mixed-methods approach conducted over one academic semester (18 weeks). The target group consisted of 22 9th-grade students enrolled in an elective STEM education course at Naresuan University Secondary Demonstration School during the 2024 academic year. The research instruments included:

1. A 5-point Likert scale questionnaire on GenAI usage and satisfaction.

2. Semi-structured interviews regarding students' experiences and perspectives on GenAI tools (e.g., ChatGPT for coding and text generation, Canva AI for presentation design).
3. Pre- and post-instruction performance assessments and self-evaluation rubrics measuring analytical thinking and problem-solving skills. Data analysis involved mean scores, standard deviations, qualitative thematic analysis, and paired-samples t-tests to compare pre- and post-learning skills.

Results

Guidelines for Using GenAI in STEM PBL

All students (100%) utilized GenAI primarily for project development and content creation. Students reported the highest level of satisfaction (mean = 4.67) due to its ease and convenience of use. GenAI played a significant role in every stage of the project—from problem analysis and planning to design and presentation—by aiding in information retrieval, code generation, and complex problem-solving. A key limitation identified was that some AI-generated information was inaccurate, requiring students to verify facts before application.

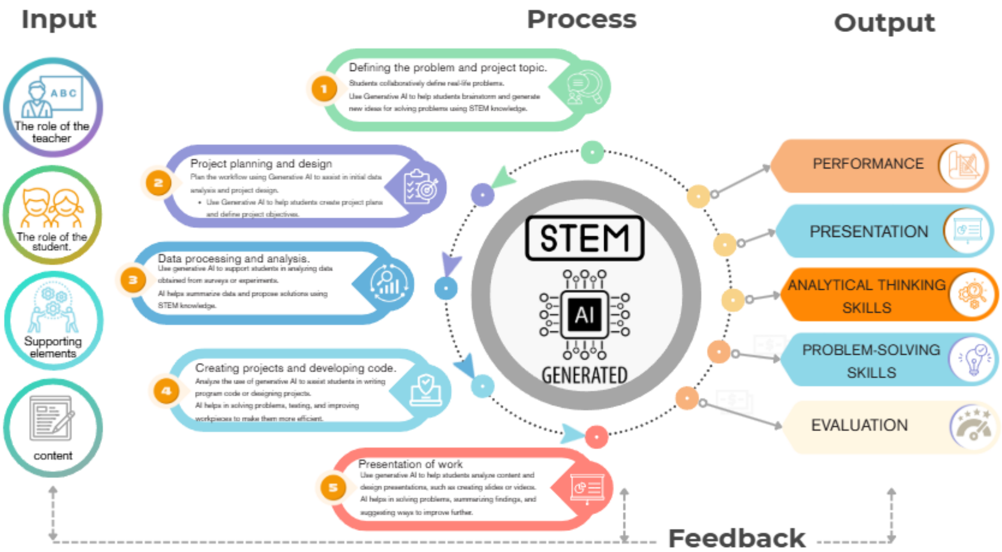
Effects on Skill Development

GenAI positively impacted students' skills by broadening their perspectives and simplifying the understanding of complex concepts. Statistical analysis revealed that students' analytical thinking and problem-solving skills were significantly higher post-instruction compared to pre-instruction at the .05 level.

Instructional Management Model

A 5-stage instructional model was developed to integrate Generative AI into STEM project-based learning. This model consists of problem identification, planning, execution/data analysis, artifact creation/code development, and presentation, as illustrated in Figure 1.

Figure 1
The 5-Stage STEM-AI Instructional Management Model



Experts evaluated this STEM-AI integrated model as highly appropriate (mean = 4.36).

Discussion

The findings align with the premise that Generative AI acts as a catalyst for deeper learning in PBL environments. By assisting with coding, design, and complex problem-solving, GenAI helps students focus on higher-order analytical thinking. However, because AI occasionally generated inaccurate information, students were required to engage in critical evaluation. This limitation transformed the nature of their critical thinking from mere knowledge acquisition to active data verification and integration, ultimately developing a more profound cognitive process.

Conclusion

Implications

For educators, the developed 5-stage model provides a clear, structured roadmap for integrating AI into classrooms. Rather than banning or ignoring AI, teachers should design learning environments where AI serves as a scaffold, while keeping human critical analysis at the center of the learning process. For curriculum developers, STEM curricula should explicitly incorporate AI literacy, prompt engineering, and fact-checking protocols alongside traditional technical subjects.

Limitations

The primary limitation identified is the risk of over-reliance. If students lack foundational science or coding knowledge, they may accept incorrect AI outputs blindly, leading to non-functional prototypes. Furthermore, this study was limited to a purposive sample of 22 students in one school, suggesting that broader, larger-scale research is needed to verify generalizability.

Recommendations

Future research should pursue longitudinal studies to assess the long-term impact of AI tools on students' independent cognitive development. Comparative studies are recommended to evaluate differing pedagogical outcomes across diverse AI interfaces. Finally, structured teacher training frameworks must be developed to equip educators with the skills needed to effectively facilitate AI-integrated STEM classrooms.

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Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the author used Google Gemini to translate, summarize, and format the manuscript from the original Thai research report into English. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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Contact email: thaweesina@nu.ac