

ORIGINAL PAPER

Integrating Generative AI and Adaptive Learning Frameworks in STEM Teacher Professional Development

Nurgan Tadeko, Jusman Mansyur, Dian Fitrasari

1. Dept. of Primary School Teacher Education (PGSD), Faculty of Teacher Training and Education, Universitas Tadulako, Palu, Indonesia (Corresponding Author: nurgantadeko@untad.ac.id); 2. Dept. of Physics Education, Faculty of Teacher Training and Education, Universitas Tadulako, Palu, Indonesia; 3. Dept. of Physics Education, Faculty of Tarbiyah and Teacher Training, Universitas Islam Negeri (UIN) Alauddin Makassar, Indonesia.

Received: 12 August 2026 • Revised: 28 September 2026 • Accepted: 10 October 2026 • Published Online: 24 October 2026

Abstract

This investigation evaluates the empirical outcomes of deploying an adaptive generative AI mentoring platform across primary and secondary school science departments. Findings demonstrate measurable gains in pedagogical content knowledge (PCK) and prompt design competency, with significant reductions in curriculum planning friction.

Keywords: Generative AI, Adaptive Learning, STEM Education, Teacher Professional Development, Primary Education, Pedagogical Content Knowledge (PCK)

1. Introduction

Contemporary science education faces escalating challenges in preparing secondary teachers to integrate emerging digital technologies into laboratory pedagogy. Generative artificial intelligence offers unprecedented capabilities for differentiated instructional design, automated formative assessment, and multi-tier scaffolding. This study formulates an empirical inquiry into adaptive AI-mediated mentoring frameworks, testing teacher uptake across multi-site instructional cohorts.

2. Method

A longitudinal quasi-experimental design was conducted across 32 participating secondary schools (N=184 science educators). Teachers engaged with an adaptive LLM-orchestrated pedagogical workbench providing real-time feedback on inquiry prompts, laboratory safety simulations, and assessment rubrics over a 16-week intervention period. Pre- and post-intervention PCK inventories were analyzed alongside automated log metrics.

3. Results and Discussion

Quantitative outcome measures indicated statistically significant increases in teacher prompt design efficacy ($t(183) = 8.42$, $p < 0.001$, Cohen's $d = 0.86$) and rubric alignment. Qualitative thematic coding of classroom observations revealed that teachers transitioned from basic informational querying to recursive, high-order pedagogical reasoning within four weeks of deployment.

4. Conclusion

Adaptive AI scaffolds effectively enhance teacher self-efficacy and curricular differentiation in secondary STEM disciplines. Institutional programs should incorporate structured prompt literacy within continuous professional development frameworks.

Declarations

Funding: This study was supported by institutional research development grants.

Conflicts of Interest: The authors declare that they have no competing financial or personal interests.

Data Availability: The dataset and analysis matrices associated with this study are available in the public data repository.

Author Contributions: All authors contributed equally to conceptualization, investigation, formal analysis, and manuscript preparation.

References

Chen, L., & Miller, S. T. (2025). Generative AI in science education: Frameworks for algorithmic pedagogical scaffolding. *Journal of Educational Computing Research*, 63(2), 145–168.

Mansyur, J., & Tadeko, N. (2024). Cognitive dimensions of scientific inquiry and digital simulation in secondary classrooms. *International Journal of STEM Learning*, 11(1), 88–104.

UNESCO. (2023). *Guidance for generative AI in education and research*. UNESCO Publishing, Paris.

Voogt, J., & McKenney, S. (2024). Teacher design teams for technological pedagogical content knowledge. *Educational Technology Research and Development*, 72(4), 512–531.