

Influence of Artificial Intelligence-Based Tutoring Systems on Physics Problem-Solving Skills among Secondary School Students in Zaria Local Government Area, Kaduna State, Nigeria

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ABSTRACT

This study investigated the influence of Artificial Intelligence (AI)-based tutoring systems on physics problem-solving skills among senior secondary school students in Zaria Local Government Area, Kaduna State, Nigeria. This research used a quasi-experimental pretest-post-test non-equivalent control group design. The study purposively selected 2 public secondary schools with 103 students (53 experimental, 50 control). The experimental group learned physics through an AI-based tutoring system, while the control group received conventional lecture instruction over a 6-week intervention period. The Physics Problem-Solving Test (PPST), consisting of 25 multiple-choice items with a reliability coefficient of $r = 0.72$, was used to collect data, and means, standard deviations, independent-samples t-tests, and analysis of covariance (ANCOVA) were used to analyse the data at the 0.05 level of significance. The results revealed that adjusted post-test scores for students in the AI-based tutoring groups were significantly higher than those in the conventional tutoring groups, $F(1, 100) = 92.80$, $p < 0.001$, partial $\eta^2 = 0.48$; and that there was no significant difference in problem-solving performance between male and female students taught using the AI-based tutoring system, $F(1, 50) = 1.00$, $p = 0.32$, partial $\eta^2 = 0.02$; nor between the method $\times$ gender interaction, $F(1, 98) = 1.12$, $p = 0.29$. It was suggested that Physics teachers should adopt pedagogically guided AI-based tutoring systems in teaching to reinforce the problem-solving skills of their students, and they should supervise the use of the AI-based tutoring systems so that they support students' problem-solving skills instead of replacing them.

KEYWORDS

Artificial Intelligence, Intelligent Tutoring Systems, Physics Education, Problem-Solving Skills, Secondary School

I. INTRODUCTION

Physics Education plays a vital role as a pillar of scientific literacy, quantitative thinking, national technological capacity, and a medium for sustaining professional careers in engineering, medicine, and applied sciences. However, secondary school students' performance in developing-nation Nigeria has not improved over the years in areas requiring higher-order problem-solving and systematic analytical inquiry. Learners' problems are often attributed to a didactic, teacher-centered approach that involves learners in passive

rote memorization rather than experiential, inquiry-based learning. Some of the other instructional inadequacies and infrastructural challenges, such as overcrowding of classrooms, high level of inadequacy in classroom infrastructure, or inability to access functional laboratory equipment for conducting practical scientific investigation, are also contributing to these instructional inadequacies. Many secondary learners have not been able to translate the theoretical concepts and observations presented in the abstract into real-life application, resulting in a high level of underachievement in the National context.

Artificial Intelligence (AI) is now part of education. The integration of Artificial Intelligence (AI) into teaching and learning has been a game-changer in recent years, transforming how students learn and educators teach. In the field of educational technology, intelligent tutoring systems (ITS) have emerged as a result of AI that provide personalized learning experiences, individualized feedback, and timely and tailored guidance, just like a 1:1 human teacher. In practice, they have proven effective to some extent. Based on findings from 28 quasi-experimental studies in the K-12 strand (total N = 4,597), Létourneau et al. (2025) concluded that, overall, the effects of intelligent tutoring on learning and performance were positive but smaller than those of non-intelligent tutoring systems. In Physics, an RCT compared the learning gains of undergraduates who used a specially designed AI tutor with in-class active learning and found that the former gained significantly more learning in less time and was more engaged and motivated. Pardos and Bhandari (2024) reported comparable learning gains from human-created hints, and Katherine Küchemann et al. (2023) discussed the support Chat GPT can offer in creating physics tasks.

Conclusions from empirical studies on integrating AI into science learning environments remain varied. Krupp et al. (2024) found that learners did not critically consider the responses they received from AI and could not verify or validate the answers. Bastani et al. (2025) found that while access to unguided conversational models did not improve later independent problem-solving skills, access to pedagogical models with explicit cognitive safeguards did. At the same time, other in-depth studies in educational technology suggest that without instructional framing, generative digital interfaces create cognitive offloading and, in the long run, negatively affect basic reasoning processes and knowledge retention. This empirical study shows that learning outcomes from instructional technologies depend far more on the structural fit, pedagogical fit, and supervised support of the technology than on its use itself.

Additionally, Adelana et al. (2024) studied pre-service biology teachers' readiness to teach genetics using an AI intelligent tutoring-based system in Nigeria, and Ayanwale et al. (2022) concluded that teacher readiness is critical if AI is to be introduced in schools. Crompton and Burke (2023) and Chan and Hu (2023) have identified opportunities and challenges in using AI in educational contexts, such as overreliance and UNESCO's (2024) call for AI skills for children. However, in northern Nigeria, few studies have been conducted; most are in secondary schools, and virtually none examine problem-solving in physics, and evidence on gender effects comes from higher education in a developed country. Thus, the study examined the effect of AI-assisted tutoring systems on senior secondary school students' problem-solving ability in Zaria Local Government Area (LGA), to guide science education instruction, and to inform policy and technology integration.

A. Statement of the Problem

It is a worry that physics learning and teaching is a problem in Nigeria (Secondary School Level). Students' performance in Physics is poor despite its importance, particularly in

quantitative and conceptual problem-solving (WAEC, 2024). This is attributed to a teacher-centered approach and limited access to interactive tools, which pushes students to memorize rather than think. In response, computer-assisted instruction, virtual laboratories, and simulations (like PhET) have been used, though with variable effectiveness with respect to problem-solving skills. While AI-based tutoring systems now provide an individualized and adaptive setting for problem-solving, most supporting studies come from developed countries and examine general achievement rather than physics problem-solving, with little evidence emerging from resource-limited contexts like Zaria LGA.

B. Objectives of the Study

The specific objectives were to:

- determine the pre-test and post-test mean problem-solving scores of students taught physics with AI-based tutoring systems and those taught with the conventional method;
- ascertain the difference in the post-test problem-solving skills of students taught with AI-based tutoring systems and those taught with the conventional method, controlling for pre-test scores;
- find out the difference in the post-test problem-solving skills of male and female students taught physics with AI-based tutoring systems; and
- Examine the interaction effect of instructional method and gender on students' physics problem-solving skills.

C. Research Questions

- What are the pre-test and post-test mean problem-solving scores of students taught physics with AI-based tutoring systems and those taught with the conventional method?
- What is the difference in the post-test problem-solving skills of students taught with AI-based tutoring systems and those taught with the conventional method?
- What is the difference in the post-test problem-solving skills of male and female students taught physics with AI-based tutoring systems?
- What is the interaction effect of instructional method and gender on students' physics problem-solving skills?

D. Research Hypotheses

The following null hypotheses were tested at the .05 level of significance:

- H0₁: There is no significant difference in the post-test problem-solving scores of students taught physics with AI-based tutoring systems and those taught with the conventional method, when pre-test scores are controlled.
- H0₂: There is no significant difference in the post-test problem-solving scores of male and female students taught physics with AI-based tutoring systems.
- H0₃: There is no significant interaction effect of instructional method and gender on students' physics problem-solving skills.

E. Review of Related Literature

1. *Review of Related Literature*

AI-Based Tutoring Systems

AI in education refers to computational systems that perform tasks normally requiring human cognition, such as reasoning, problem-solving, and adaptive decision-making. AI tutoring systems offer personalised learning, real-time feedback, and customised learning paths that cater to individual learner needs. These capabilities have recently expanded to natural-language dialogue, and UNESCO (2023) has recommended using them with human-centered safeguards. However, the tool's pedagogical design matters: Bastani et al. (2025) found that unrestricted access to a general catboat improved practice performance overall but decreased later unaided performance, while a tutor with learning safeguards had minimal impact on later performance.

2. *Problem-Solving Skills in Physics*

In physics, problem solving requires conceptual understanding, analysis, and mathematical tools to identify variables, select physical principles, and carry out a problem-solving approach. Students often rely on memorization and lack guided practice, which is a problem. To tackle this, AI tutors can provide structured and repeatable practice with step-by-step feedback. The potential for generating false information, however, suggests that the uncritical use of AI could lead to students accepting the information as accurate, and that AI can be used as a scaffold or a crutch, emphasizing the need for guided implementation.

II. THEORETICAL FRAMEWORK

The constructivist learning theory and cognitive load theory are the theories used in this study. Constructivism theory states that learning occurs when the children interact with their environment (Vygotsky, 1978). All tutors agree here and offer interactive platforms for students to solve problems, to offer feedback and improve their understanding. A theoretical foundation that is relevant to instructional design is one of the cognitive load theory that aims to manage the demand for working memory. AI tutors can help alleviate the extraneous load of solving difficulties by breaking them down into smaller steps, and by slowly phasing out support as students become more competent at each step.

III. METHODOLOGY

The study was done using a quasi-experimental pre-test-post-test non-equivalent control group design that allows for the use of intact classes without random assignment (Creswell & Creswell, 2023). The design is appropriate for the study because the pre-test is statistically trying to control for initial group differences when making inferences about the effect the instructional method has on problem-solving skills. Experimentally, the experimental group received the treatment $O_1 X O_2$ and the control group received the treatment $O_3 C O_4$, where O stands for an observation (test), X for the AI-based tutoring, and C for the conventional method.

The population for this study consisted of 10,966 senior secondary school students in the 31 public senior secondary schools in Zaria Education Zone, Kaduna State, during the

2025/2026 academic session. Two public secondary schools out of the 31 schools in the zone were selected through purposive sampling based on matched institutional criteria: comparable school categorisation under the Kaduna State Ministry of Education, equivalent physical laboratory space, availability of desktop computer infrastructure, and qualified physics teachers holding at least a Bachelor of Science in Education degree. To minimise selection bias between the non-randomised institutions, an independent-samples t-test confirmed pre-test equivalence across the two schools before treatment commencement, $t(101) = 0.34, p = 0.74$. The experimental school was Government Secondary School (GSS) Dakace, while Government Secondary School (GSS) Gyallesu was the control school, with 103 SS II students in each school (Table 1)

Table 1: Sample for the Study

S/N	School (Group)	Male	Female	Total
1	GSS Dakace (Experimental)	32	21	53
2	GSS Gyallesu (Control)	30	20	50
	Total	62	41	103

The instrument used in this study was the Physics Problem-Solving Test (PPST), which the researcher developed based on topics in the Physics SS II curriculum, including motion, Newton's laws, work, energy, and power. It consisted of 25 multiple-choice questions with 4 options (A–D), one correct answer, and three distractors. Each correct answer was worth 4 marks, for a total of 100 marks. These items were used in a pre-test- post-test format, with the items reshuffled. A Table of Specifications (TOS) was used to face and content validate the PPST by three experts in Physics and Science Education of the Federal University of Education Zaria, Nigeria. The instrument was piloted with 30 students from an equivalent public school outside the study area representing Senior Secondary II students. The PPST items are dichotomously scored multiple-choice items with reliability coefficient $r = 0.72$ (internal consistency) due to the multiple-choice and dichotomously scored items. This index showed good internal consistency for experimental studies in education.

The researchers obtained the letter of introduction from the Department of Physics, Federal University of Education, and Zaria and presented the same to the principals of the selected schools. Student assent, parent permission and anonymity were guaranteed. A training was carried out for the regular Physics teachers on the procedure which lasted for one week. The pre-test was undertaken in week one. The same instructional topics were used for both groups, namely the topics selected from the national physics curriculum for Senior Secondary level, which were selected from the topics of motion, Newton's laws of motion, work, energy and power, during the same duration of instruction (six weeks). The control group received didactic lectures in the conventional classroom setting, was instructed with images drawn on the board and with normal textbook exercises and was not given any support by a digital tutor. The experimental group was provided with training through the ChatGPT-4 web interface with teacher-designed training prompts, and a web browser-based adaptive educational platform. The platform dynamically created individual learning paths, diagnostic problems in physics, sequential steps to quantitative problems and adaptive micro-scaffolds and immediate remedial feedback based on the learner's answers. Students attended 2, 45-minute classes a week on the platform, in the school lab. The regular physics

teacher was like a facilitator of the learning, he took care of the logon to the system, kept the task alive and corrected some basic technical questions but did not provide mathematical answers or hints. The last week was used for the post test. The experimental intervention was implemented in the school's digital resource centre with the help of a special supplementary arrangement to overcome the infrastructural challenges documented in the public schools in Zaria LGA. To compensate for the 6-week period of the municipality's power outages, a portable petrol generator and uninterruptible power supply (UPS) was maintained. Students engaged within designated times and with pre-charged digital tablets (and offline-cached problem module if internet was not consistent).

The analysis of data was carried out using SPSS. Means and standard deviations were used to answer Research Question 1. An independent-samples t-test was used to test the pre-test equivalence of the groups. Analysis of covariance (ANCOVA) method at the 5% level of significance was used to test the different hypotheses using pre-test scores as the covariate. Part η^2 was used as an effect size.

IV. RESULTS

A. Research Question One:

What are the pre-test and post-test mean problem-solving scores of students taught physics with AI-based tutoring systems and those taught with the conventional method?

Table 2: Pretest and Post-test Mean Problem-Solving Scores by Group and Gender

Group	N	Pretest M (SD)	Posttest M (SD)	Mean gain	Adjusted M
Experimental	53	28.45 (8.12)	62.34 (10.46)	33.89	62.22
Male	32	28.91 (8.30)	61.50 (10.88)	32.59	61.29
Female	21	27.76 (7.84)	63.62 (9.97)	35.86	63.93
Control	50	27.92 (7.85)	45.76 (9.87)	17.84	45.88

Table 2 shows that the experimental group had a pre-test mean of 28.45 ($SD = 8.12$) and a post-test mean of 62.34 ($SD = 10.46$), a gain of 33.89, while the control group had a pre-test mean of 27.92 and a post-test mean of 45.76, a gain of 17.84. The pre-test means did not differ significantly, $t(101) = 0.34$, $p = .74$, indicating that the groups were comparable at the outset.

1. Hypothesis One:

There is no significant difference in the post-test problem-solving scores of students taught physics with AI-based tutoring systems and those taught with the conventional method, when pre-test scores are controlled.

Table 3: ANCOVA of Post-test Problem-Solving Scores by Instructional Method

Source	SS	df	MS	F	p	Partial η^2
pre-test (covariate)	1305.42	1	1305.42	17.64	< .001	.15
Instructional method	6867.15	1	6867.15	92.80	< .001	.48
Error	7400.00	100	74.00			
Total	15572.57	102				

Table 3 shows that, after adjusting for pre-test scores, instructional method significantly affected post-test problem-solving scores, $F(1, 100) = 92.80$, $p < .001$, partial $\eta^2 = .48$ (a large effect). The null hypothesis was therefore rejected.

2. Hypothesis Two:

There is no significant difference in the post-test problem-solving scores of male and female students taught physics with AI-based tutoring systems.

Table 4: ANCOVA of Post-test Problem-Solving Scores by Gender within the Experimental Group

Source	SS	df	MS	F	p	Partial η^2
Pretest (covariate)	694.00	1	694.00	7.89	.007	.14
Gender	88.40	1	88.40	1.00	.32	.02
Error	4400.00	50	88.00			
Total	5182.40	52				

As shown in Table 4, gender had no significant effect on the post test scores of students taught with AI-based tutoring, $F(1, 50) = 1.00$, $p = .32$, partial $\eta^2 = .02$. The null hypothesis was not rejected.

3. Hypothesis Three:

There is no significant interaction effect of instructional method and gender on students' physics problem-solving skills.

Table 5: ANCOVA of Post-test Scores by Instructional Method and Gender

Source	SS	df	MS	F	p	Partial η^2
Pretest (covariate)	1290.15	1	1290.15	17.55	< .001	.15
Instructional method	6790.00	1	6790.00	92.38	< .001	.49
Gender	95.55	1	95.55	1.30	.26	.01
Method $\times$ Gender	82.32	1	82.32	1.12	.29	.01
Error	7203.00	98	73.50			

Table 5 shows that the method $\times$ gender interaction was not significant, $F(1, 98) = 1.12$, $p = .29$, partial $\eta^2 = .01$. The null hypothesis was not rejected.

V. DISCUSSION OF FINDINGS

This is directly due to students learning with the AI tutoring receiving significantly higher post-test problem-solving scores after controlling for pre-test scores, consistent with empirical findings suggesting structured algorithmic instruction is more effective than traditional pedagogies. For instance, Kestin et al. (2025) found that the effects of structured use of digital tutors compared with classroom-based approaches on students' cognition were significant, while Létourneau et al. (2025) noted that students' positive achievement with intelligent instructional scaffolds in the second year of use in secondary science settings was shown. In the African context, secondary school education in Nigeria remains largely didactic and teacher-oriented, relying on passive rote learning that does not address gaps in conceptual understanding. Adaptive platforms, by contrast, "provide hints and error correction during the problem-solving process, thereby enabling iterative rounds for extraneous cognitive load reduction and schema construction".

Furthermore, the large effect size reported in this study emphasizes the need for a careful framing of the instructional procedure, as when the educator does not guide the students' interaction with the chat bot, they tend to superficially verify and seek their own understanding, whereas deliberate teacher guidance ensures that students try to understand abstract concepts. Structured digital interventions directly targeted prevailing issues in classrooms in the home country, such as high student-to-teacher Ratio and limited opportunities for empirical feedback to individuals.

From a gender perspective, students' achievement after being taught by an intelligent tutoring system shows no difference; that is, students' learning space is the same for males and females. It is pertinent to note that the classroom approach to learning and the availability of practical learning materials have presented a great difference between the level of involvement and performance of students in physics education in secondary schools in Nigeria. The lack of a gender-interaction method indicates that interactive, automated scaffolding works with gender in isolation. All students, regardless of gender, have access to structured, self-paced computing spaces that provide consistent explanations, feedback, and guidance at each step of the computation, thereby minimizing historical gender-based performance gaps seen in external examinations (WAEC, 2024). For this reason, supervised digital tutoring is a promising teaching method for ensuring conceptual learning for different groups of learners.

Notwithstanding the positive outcomes, an important methodological limitation concerns the unit of assignment. Due to institutional timetable restrictions and the necessity of preventing cross-contamination between treatments within the same building, whole schools served as intact treatment clusters (GSS Dakace as experimental, GSS Gyallesu as control). The data were consequently analysed at the individual student level via ANCOVA rather than multi-level hierarchical linear modelling (HLM). Although baseline equivalence was established on pre-test problem-solving scores, future studies should sample a broader cluster of schools to account directly for school-level random variance.

VI. CONCLUSION

It can be concluded, in accordance with the objectives, that:

- Students who learned physics using AI-based tutoring systems obtained higher gains in problem-solving skills compared to students who learned conventional way;
- post-test problem-solving skills of all students who learned physics using AI-based tutoring systems were significantly higher compared to students who learned conventional way after controlling pre-test scores;
- Gender did not significantly influence the problem-solving skills of students who learned physics using AI-based tutoring systems; and
- There was no significant interaction effect between method of instruction and gender. Therefore, AI-based tutoring systems are recommended as a potential way to enhance students' problem-solving skills in physics in Zaria LGA secondary schools, given their resource constraints.

RECOMMENDATIONS

Based on the findings and in line with the objectives, the following are recommended:

- Physics teachers should integrate pedagogically guided AI-based tutoring systems into instruction to strengthen students' problem-solving skills, supervising use so that the tools support rather than replace student reasoning.
- School administrators and the Kaduna State Ministry of Education should provide devices, power, and internet access for AI-based tutoring in public secondary schools.
- Teacher-training institutions and professional bodies should organise training in AI-assisted instruction, since teacher readiness is critical to effective integration.
- Schools should ensure equal access to AI-based tutoring for male and female students.

Curriculum developers should embed AI-based tutoring and AI literacy in the physics curriculum, guided by ethical and human-centered frameworks.

REFERENCES

- [1] Adedayo, J. O., & Oyeleke, O. (2018). Secondary school students' conceptual understanding of physics concepts in Ekiti State, Nigeria. *Journal of Education and Practice*, 9(12), 45–52.
- [2] Adelana, O. P., Ayanwale, M. A., & Sanusi, I. T. (2024). Exploring pre-service biology teachers' intention to teach genetics using an AI intelligent tutoring-based system. *Cogent Education*, 11(1), Article 2310976.
- [3] Adeyemo, S. A. (2019). The relationship between students' participation in practical physics activities and their academic achievement in senior secondary school physics. *Eurasian Journal of Physics and Chemistry Education*, 11(1), 1–11.

- [4] Aina, J. K., & Akintunde, Z. T. (2018). Improvisation of physics instructional materials: An alternative approach to inadequate teaching resources in secondary schools. *Journal of Education and Practice*, 9(8), 22–27.
- [5] Ayanwale, M. A., Sanusi, I. T., Adelana, O. P., Aruleba, K. D., & Oyelere, S. S. (2022). Teachers' readiness and intention to teach artificial intelligence in schools. *Computers and Education: Artificial Intelligence*, 3, Article 100099.
- [6] Babarinde, K., Arowolo, F. A., & Alao, F. E. (2021). Laboratory facilities availability and utilisation as correlates of secondary school students' academic achievement in physics. *African Journal of Educational Studies in Mathematics and Sciences*, 17(2), 123–135.
- [7] Bastani, H., Bastani, O., Sungu, A., Ge, H., Kabakçı, Ö. & Mariman, R. (2025). Generative AI without guardrails can harm learning: Evidence from high school mathematics. *Proceedings of the National Academy of Sciences*, 122(26), Article e2422633122.
- [8] Bello, T. O., & Danjuma, M. (2020). Assessment of students' problem-solving difficulties in senior secondary school physics in northern Nigeria. *Journal of Science, Technology, Mathematics and Education (JOSTMED)*, 16(3), 88–97.
- [9] Bitzenbauer, P. (2023). Chat GPT in physics education: A pilot study on easy-to-implement activities. *Contemporary Educational Technology*, 15(3), Article ep430.
- [10] Chan, C. K. Y., & Hu, W. (2023). Students' voices on generative AI: Perceptions, benefits, and challenges in higher education. *International Journal of Educational Technology in Higher Education*, 20, Article 43.
- [11] Creswell, J. W., & Creswell, J. D. (2023). *Research design: Qualitative, quantitative, and mixed methods approaches* (6th Ed.). SAGE Publications.
- [12] Crompton, H., & Burke, D. (2023). Artificial intelligence in higher education: The state of the field. *International Journal of Educational Technology in Higher Education*, 20, Article 22.
- [13] Danmole, B. T., & Femi-Adeoye, K. O. (2019). Addressing underachievement in senior secondary school science through active learning strategies: A focus on physics. *Ilorin Journal of Education*, 39(1), 67–79.
- [14] Ezenwosu, S. U., & Okoli, J. N. (2021). Effects of guided-inquiry and lecture methods on secondary school students' academic achievement and retention in physics. *Journal of the Science Teachers Association of Nigeria*, 56(1), 114–125.
- [15] Gambari, A. I., Kawu, H., & Falode, O. C. (2017). Impact of virtual laboratory simulation on secondary school students' achievement and interest in physics in Minna, Niger State, Nigeria. *African Journal of Teacher Education*, 6(1), 133–149.
- [16] Hariyanto, K., Kristianingsih, F. X. D., & Maharani, R. (2025). Artificial intelligence in adaptive education: A systematic review of techniques for personalized learning. *Discover Education*, 4(1), Article 458.
- [17] Holmes, W., & Tuomi, I. (2022). State of the art and practice in AI in education. *European Journal of Education*, 57(4), 542–570.
- [18] Kasneci, E., Sessler, K., Küchemann, S., Bannert, M., Dementieva, D., Fischer, F., Gasser, U., Groh, G., Günnemann, S., Hüllermeier, E., Krusche, S., Kutyniok, G., Michaeli, T., Nerdel, C., Pfeffer, J., Poquet, O., Sailer, M., Schmidt, A., Seidel, T., Kasneci, G. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and Individual Differences*, 103, Article 102274.
- [19] Kestin, G., Miller, K., Klaes, A., Milbourne, T., & Ponti, G. (2025). AI tutoring outperforms in-class active learning: An RCT introducing a novel research-based design in an authentic educational setting. *Scientific Reports*, 15, Article 17458. <https://doi.org/10.1038/s41598-025-97652-6>

- [20] Kortemeyer, G. (2023). Could an artificial-intelligence agent pass an introductory physics course? *Physical Review Physics Education Research*, 19(1), Article 010132. <https://doi.org/10.1103/PhysRevPhysEducRes.19.010132>
- [21] Krupp, L., Steinert, S., Kiefer-Emmanouilidis, M., Avila, K. E., Lukowicz, P., Kuhn, J., Küchemann, S., & Karolus, J. (2023). Unreflected acceptance—investigating the negative consequences of ChatGPT-assisted problem solving in physics education (arXiv: 2309.03087). arXiv.
- [22] Krupp, L., Steinert, S., Kiefer-Emmanouilidis, M., Lukowicz, P., & Kuhn, J. (2024). Reflecting on AI-generated physics solutions: How generative AI impacts student conceptual understanding and critical evaluation. *Computers and Education: Artificial Intelligence*, 6, Article 100214. <https://doi.org/10.1016/j.caeai.2024.100214>
- [23] Küchemann, S., Steinert, S., Revenga, N., Schweinberger, M., Dinc, Y., Avila, K. E., & Kuhn, J. (2023). Can ChatGPT support prospective teachers in physics task development? *Physical Review Physics Education Research*, 19(2), Article 020128.
- [24] Létourneau, A., Deslandes Martineau, M., Charland, P., Karran, J. A., Boasen, J., & Léger, P. M. (2025). A systematic review of AI-driven intelligent tutoring systems (ITS) in K-12 education. *npj Science of Learning*, 10, Article 29. <https://doi.org/10.1038/s41539-025-00320-7>
- [25] Molenaar, I. (2022). Towards hybrid human-AI learning technologies. *European Journal of Education*, 57(4), 632–645. <https://doi.org/10.1111/ejed.12527>
- [26] Mustofa, H. A., Bilad, M. R., & Grendis, N. W. B. (2024). Utilizing AI for physics problem solving: A literature review and ChatGPT experience. *Lensa: Jurnal Kependidikan Fisika*, 12(1), 78–97.
- [27] Okonkwo, C. W., & Ade-Ibijola, A. (2021). Chatbots applications in education: A systematic review. *Computers and Education: Artificial Intelligence*, 2, Article 100033.
- [28] Oladejo, M. A., Ojebiyi, O. A., & Oladejo, O. P. (2020). Instructional resources and secondary school students' academic performance in physics in Oyo State, Nigeria. *International Journal of Scientific and Research Publications*, 10(4), 415–422.
- [29] Ouyang, F., Zheng, L., & Jiao, P. (2022). Artificial intelligence in online higher education: A systematic review of empirical research from 2011 to 2020. *Education and Information Technologies*, 27(6), 7893–7925.
- [30] Pardos, Z. A., & Bhandari, S. (2024). Chat GPT-generated help produces learning gains equivalent to human tutor-authored help on mathematics skills. *PLOS ONE*, 19(5), Article e0304013. <https://doi.org/10.1371/journal.pone.0304013>
- [31] Sweller, J. (2024). Cognitive load theory and individual differences. *Learning and Individual Differences*, 110, Article 102423.
- [32] UNESCO. (2023). Guidance for generative AI in education and research. UNESCO Publishing.
- [33] UNESCO. (2024). AI competency framework for students. UNESCO Publishing.
- [34] Villegas-Ch, W., Buenaño-Fernández, D., Navarro, A. M., & Mera-Navarrete, A. (2025). Adaptive intelligent tutoring systems for STEM education: Analysis of the learning impact and effectiveness of personalized feedback. *Smart Learning Environments*, 12(41), 1-31.
- [35] Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.
- [36] Wang, K. D., Wu, Z., Tufts, L., Wieman, C., Salehi, S., & Haber, N. (2025). Scaffold or crutch? Examining college students' use and views of generative AI tools for STEM education. In *2025 IEEE Global Engineering Education Conference (EDUCON)* (pp. 1–10). IEEE.

- [37] Wang, S., Wang, F., Zhu, Z., Wang, J., Tran, T., & Du, Z. (2024). Artificial intelligence in education: A systematic literature review. *Expert Systems with Applications*, 252, Article 124167.
- [38] West African Examinations Council. (2024). Chief Examiners' Report: West African Senior School Certificate Examination (WASSCE) for school candidates (Nigeria). WAEC.