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Artificial intelligence as a pedagogical companion for STEM research learning in higher education

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Abstract

In many higher education contexts, particularly across Africa, the process of learning how to conduct research in science, technology, engineering, and mathematics (STEM) remains both cognitively demanding and structurally under-supported. Students often encounter limited supervision, delayed feedback, and minimal mentoring, conditions that restrict their growth as independent researchers. The widening gap between students and academic mentors has created frustration, anxiety, and disengagement. This paper rethinks STEM research learning in higher education by exploring the emerging role of artificial intelligence (AI) as a pedagogical companion rather than a replacement for human instruction. Drawing on peer-reviewed literature, the paper conceptually discusses how AI-powered tools can serve as companions in research-based learning, offering real-time support, cognitive scaffolding, writing assistance, and iterative feedback. Guided by Vygotsky's Zone of Proximal Development and Cognitive Apprenticeship Theories, this paper examines how AI might enable students to access intellectual companionship in the absence of immediate supervision. The discussion spans issues of access, equity, ethical use, epistemological risks, and the socio-technical realities of AI integration in African higher education institutions. Key implications for policy, pedagogy, and capacity building are also discussed. The paper advocates a shift from rigid instructor-led paradigms to flexible, student-responsive research support ecosystems where AI technologies enhance, rather than replace, human pedagogical relationships. Ultimately, the paper positions AI not as a miracle solution, but as a complementary agent that can mediate the distance between curiosity and research mastery in STEM education.

Keywords STEM research learning, Artificial intelligence, Higher education, Pedagogical companion, Africa, Supervision, Academic writing

1 Introduction

"I have many questions to ask, but the teacher is too far." This sentence represents a familiar frustration among higher education students, a moment when curiosity meets the absence of a teacher and as such, learning cannot take place. In most higher



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institutions in Africa, especially in Nigeria, the process of learning how to do research in science, technology, engineering, and mathematics (STEM) remains a significant challenge for students. Many arrive with great interest and aspirations, but struggle with the demands of academic research, writing, and publication [97]. They often encounter conceptual, methodological, and analytical dilemmas in their research journey, yet find no one nearby to answer their questions. Supervisors are few and overburdened, often exceeding recommended teaching and supervision loads, while institutional support for research learning is scarce and, in some cases, absent [95]. This lack of access to experienced mentors leaves many students feeling isolated, confused, and underprepared for independent research.

The problem is more pronounced in STEM fields, where the learning process requires a deeper grasp of research design, data analysis, logical reasoning, and experimental thinking [39, 92]. As students wrestle with uncertainty, many turn to digital spaces and artificial tools for answers, signaling a potential shift in the pedagogy of research learning [76, 130]. With applications like ChatGPT and other intelligent assistants increasingly assuming the role of academic guide, it becomes urgent to rethink how research learning occurs in higher education, especially when the teacher, physically or cognitively, is too far from the student with many questions to ask.

Artificial Intelligence (AI), once seen as a threat to traditional education, is gradually being reconsidered as a possible support system, particularly for knowledge-building activities [19, 47, 50, 99]. Tools such as ChatGPT, Claude, and Elicit are increasingly being used to support students across various research tasks, including idea generation, literature exploration, article summarisation, argument critique, and explanatory support [122, 128]. Their interactive and responsive nature positions them as potential companions for students navigating the complexities of STEM research. When students are properly guided, generative AI tools like ChatGPT and Elicit can provide valuable support in the early stages of research. Some scholars have noted that they help with tasks such as developing ideas, searching for literature, and synthesizing evidence, especially in learning environments with limited access to resources [25, 128]. Thus, in a situation where many Nigerian students lack access to supervisors and digital libraries, the use of AI is not merely a convenience; it is increasingly a necessity.

Several scholars argue that AI can help bridge the gap between theoretical knowledge and practical application when thoughtfully integrated into higher education [33, 57]. For instance, AI tools can complement traditional teaching, especially in large classes where personalized feedback is rare. Recently, Villegas-Ch et al. [123] found that advanced adaptive learning systems in STEM education improve learning outcomes through real-time feedback and active problem-solving. Moreover, a pilot study with engineering undergraduates found that ChatGPT improved the quality of lab report revisions, enhancing critical thinking, rhetorical awareness, and adherence to engineering conventions [54]. Despite these promising findings, most research focuses on general learning support or ethical debates. Few studies examine how AI can specifically support learning in academic research [102], especially in STEM disciplines at African universities. This gap is important to address, as international emphasis on research innovation and scholarly output places African institutions at a pivotal point of growth.

The gap is also concerning given the rapid expansion of generative AI tools, which are reshaping how students approach knowledge acquisition and research competence.

While concerns around plagiarism, intellectual laziness, and overreliance on machine-generated content remain valid [93], emerging evidence shows that, when properly guided, students can use AI to enhance critical thinking [118] and creativity in research tasks [45], which are some benefits [99]. In many African universities, however, the absence of appropriate frameworks for integrating AI into research learning risks turning potential benefits into liabilities. Without clear guidance, students may either misuse these tools or fail to develop essential scholarly habits.

Addressing this challenge requires more than cautious optimism; it demands deliberate action. This paper explores how generative AI tools can serve as pedagogical companions in STEM research learning, particularly within African higher education contexts. It examines the opportunities and risks associated with AI-assisted research learning and reviews emerging practices. It applies two theoretical anchors: Vygotsky's Zone of Proximal Development and Cognitive Apprenticeship Theory to rethink the structure of academic mentorship in an AI-mediated environment. Ultimately, the paper proposes a framework for integrating AI into research learning that aligns machine assistance with human mentorship, preserving scholarly rigor while expanding access and support.

2 Methodological approach

This paper adopts a conceptual and argumentative approach grounded in critical engagement with existing literature on artificial intelligence in higher education, STEM research learning, research supervision, and pedagogical innovation. Rather than generating primary empirical data, the paper synthesizes contemporary scholarship to examine the opportunities, limitations, ethical concerns, and pedagogical implications of integrating AI into STEM research learning environments [11, 21, 107].

Relevant literature was purposively selected from peer-reviewed journal articles, theoretical papers, policy discussions, and recent studies on generative artificial intelligence in education. Particular attention was given to studies addressing AI-supported feedback systems, intelligent tutoring, postgraduate supervision, digital inequality, academic integrity, and ethical concerns within African and Global South higher education contexts [3, 129]. The paper does not claim systematic-review status; instead, it draws on influential and recent scholarship to develop a theory-informed discussion and to propose pedagogical and institutional directions for responsible AI integration in STEM research learning.

3 Theoretical underpinning

This paper draws on two complementary learning theories: Vygotsky's Zone of Proximal Development and the Cognitive Apprenticeship Theory. These frameworks explain how AI tools can serve as companions for STEM research learning, particularly when human supervision is limited or remote.

3.1 Vygotsky's zone of proximal development and scaffolding [124]

Vygotsky's theory posits that learning takes place between what students can do independently and what they can achieve with guidance from a more capable other. Learning in this zone relies on social interaction, dialogue, and the gradual release of support [22, 124]. Scaffolding involves offering help aligned with the student's current competence

and reducing this support as understanding improves. Research confirms that these principles support critical thinking and intellectual development in formal learning settings [14, 115]. In higher education, especially in resource-limited African institutions, students often lack consistent access to research supervision. Within this gap, AI tools can function as proxies for the “more knowledgeable other,” guiding students through search, synthesis, drafting, and revision tasks. These tools facilitate reflection and step-wise progression, such as personalized mentorship [13]. The key assumptions of ZPD are:

1. Learners possess prior knowledge that can be expanded with help.
2. Advancement requires a knowledgeable source of support.
3. Support should adjust to match performance levels.

AI can help actualize these assumptions when supervision is unavailable or inconsistent. For instance, natural language processing systems can generate feedback, prompt critical questions, or scaffold writing tasks in real time. In their systematic review of 158 studies, Cai et al. [13] found that AI applications aligned with ZPD principles increased student motivation, supported self-assessment, and improved performance in research tasks.

3.2 Cognitive apprenticeship theory [17]

Cognitive Apprenticeship Theory stresses learning through guided participation in real tasks. It proposes that students develop expertise when exposed to expert modeling, supported practice, and opportunities for reflection [17]. Learning must occur in authentic settings, with access to expert thinking and the progressive reduction of support [12]. This theory is relevant for STEM research, where students often struggle with hidden or tacit elements of the research process. Expert modeling and situated guidance help demystify how to develop questions, evaluate sources, construct arguments, and revise work [61, 103]. When such guidance is unavailable, AI can simulate these processes. The key assumptions of this theory include:

1. Thinking processes must be made visible through modeling.
2. Learning is grounded in real-world practice.
3. Independence is achieved by gradually removing support.

Research shows that AI tools can simulate cognitive apprenticeship by offering contextual feedback, prompting reasoning, and modeling decision-making. For instance, Wagner et al. [125] found that AI tools can support research learning by guiding users through hypothesis development, literature review, and methodological planning, while also providing feedback and simulating expert reasoning. Similarly, Ding et al. [28] found that peer-led and expert-guided lab activities significantly enhanced undergraduates’ research abilities. When designed with apprenticeship principles, AI can provide consistent guidance, especially in under-supervised environments.

4 STEM research learning in higher education

STEM research learning in higher education is central to fostering innovation, critical thinking, and scientific progress. This section explains its key principles, why it matters, and the ongoing challenges that affect its effectiveness.

4.1 STEM research learning in the university context

STEM research learning in higher education involves the cognitive, technical, and collaborative processes through which students in Science, Technology, Engineering, and Mathematics acquire the skills, discipline, and mindset needed for rigorous research. It takes place through both formal and informal means, such as coursework, laboratory work, collaborative projects, mentorship, and academic writing. The focus is not just on mastering content, but on developing scientific thinking, research ethics, technological fluency, and the ability to pose, test, and refine hypotheses in line with disciplinary standards. In STEM fields, research learning is typically inquiry-based, project-driven, and shaped by collaborative or apprenticeship-like settings. It requires students to engage with theoretical and methodological complexities, pushing them toward independent investigation [1]. Unlike conventional learning, it demands consistent supervision, ongoing feedback, access to research tools, and an environment that supports experimentation, reflection, and iterative improvement [17, 83].

4.2 The Importance of STEM research learning in higher education

In universities, especially across the global South, STEM research and learning remain a vital channel for generating knowledge that addresses national and regional development challenges. It fosters critical thinking, problem-solving, creativity, and the capacity to contribute meaningfully to scholarly discourse and technological advancement [77]. In many African countries, where higher education institutions function as engines of national development, strengthening research capacity in STEM is directly linked to addressing pressing challenges in health, agriculture, energy, environment, and industry [127]. Beyond national imperatives, research learning plays a pivotal role in shaping students' scholarly identity and confidence. Active engagement in research enhances deep learning, builds self-efficacy, and improves academic performance [62]. In STEM fields, such engagement is particularly significant, as it is associated with increased publication output, participation in innovation ecosystems, and employability in knowledge-driven sectors [78]. The value of STEM research learning extends well beyond individual academic success; it contributes to national research productivity, global competitiveness, and the development of sustainable innovation systems [77, 127].

4.3 Supervision, mentorship, and the role of inquiry

Effective STEM research learning depends significantly on the quality and accessibility of supervision and mentorship. Supervision offers the intellectual and emotional guidance students need to navigate complex research tasks, while mentorship supports long-term academic growth, professional identity formation, and access to research networks. Through this relationship, students develop scholarly habits, internalize disciplinary norms, and learn to write for publication with critical awareness [17, 83]. Research learning, rooted in inquiry-based approaches, requires an environment where students can pose questions, test ideas, and receive consistent feedback. In STEM fields, this process is even more demanding. Students must learn to operate technical equipment, analyze data using specialized tools, and conduct experiments that require accuracy, rigor, and ethical sensitivity. In the absence of regular interaction with supervisors or research-active faculty, many students struggle to develop these competencies, leading to delays, disengagement, or withdrawal from research programs.

4.4 Current barriers to STEM research learning in Africa

Despite the central role of research in STEM education, students at many African universities face deep-rooted structural and institutional barriers that hinder their engagement with research. A major constraint is the shortage of qualified and accessible supervisors. High supervisor-to-student ratios, driven by academic brain drain and inadequate postgraduate training pipelines, often leave students without meaningful guidance for extended periods [120]. Poor infrastructure further aggravates the problem. Many laboratories are poorly equipped, outdated, or in disrepair. Access to essential resources such as research databases, scientific journals, software tools, and stable internet remains limited [81]. These deficits undermine students' ability to conduct empirical investigations or literature-based research, significantly affecting both skill development and research output. In STEM disciplines, where learning is largely practice-based, such constraints directly impair academic growth. Moreover, research is weakly embedded in many undergraduate programs. In several institutions, it is treated as a peripheral activity rather than a core component of learning, leading to poor research culture and limited exposure to methodologies, even at advanced levels [119]. Among postgraduate students, the absence of structured research learning models and sustained mentorship leads research to be pursued largely as a graduation requirement rather than as a pathway to scholarly identity and inquiry.

4.5 Cultural and structural barriers to supervision

In African higher education systems, cultural and structural barriers to supervision pose significant challenges to STEM research learning. Hierarchical academic cultures often discourage students from questioning supervisors or pursuing independent inquiry, both of which are essential to research. When supervisors are seen as distant or authoritarian, creativity and open academic dialogue are suppressed. Supervisory structures also face systemic problems. Many supervisors are overburdened, poorly remunerated, and lack institutional incentives for quality mentorship. In some cases, supervision is viewed as a routine obligation rather than a teaching responsibility, leading to minimal feedback, delayed responses, and weak accountability [106]. Gendered power relations and social exclusion further limit access to effective supervision, especially for women and students from marginalized backgrounds [29, 109]. Traditional face-to-face supervision methods are increasingly inadequate amid rising enrolment and limited faculty capacity [60]. Physical separation between supervisors and students, common in part-time and sandwich programs, hampers regular interaction, weakens feedback mechanisms, and undermines motivation [88, 121]. These realities highlight the need for alternative or complementary models, such as AI-supported mentorship, to expand access and improve research learning outcomes.

4.6 The role of artificial intelligence in closing research learning gaps

Artificial Intelligence (AI) offers new ways to support research learning, especially in STEM fields [21, 131]. In many Nigerian universities, students struggle to receive timely help from supervisors due to staff shortages and heavy workloads [60]. AI tools such as ChatGPT, virtual research assistants, and intelligent tutoring systems now provide support by giving feedback on writing, helping organize ideas, and even suggesting research directions [49, 68]. These tools do not replace supervisors but assist students when

human help is not available [21]. AI can help students find relevant literature, improve their writing, and think critically [30, 110]. This is especially useful for students in rural or underfunded institutions. However, to benefit fully, students and lecturers must first have access to stable internet and a good power supply, something many institutions still lack. There is also a need to train supervisors and students in the ethical and responsible use of AI [5, 126]. If these challenges are addressed, AI can reduce stress, guide students in designing quality research, and improve completion rates. This can also lead to more publications and boost universities' image [5, 21]. AI should be seen as a learning partner, not just a machine, that helps students think better and do research with more confidence.

5 Artificial intelligence in higher education: present capacities

This section examines how AI is currently used in universities, particularly in supporting STEM research and learning. It focuses on tools such as ChatGPT, Elicit, and Semantic Scholar AI, while also pointing out their limitations, risks, and ethical concerns. The aim is to give a clear picture of what AI is doing now and how it could support research learning in the future.

5.1 Artificial intelligence in teaching and learning

Artificial Intelligence (AI) is now changing the way higher education works. It is helping to improve teaching and learning processes and making academic work easier. In many classrooms, AI tools are now used to deliver content, mark assessments, give personalized feedback, and handle administrative tasks. Tools like intelligent tutoring systems, adaptive learning platforms, and virtual assistants adjust lessons based on how students perform and engage [131]. In countries such as the United Kingdom and the United States, and across Asia, AI platforms help lecturers manage large classes, send messages, and quickly and fairly mark both small-scale tests and large-scale exams [27]. Tools for automatic marking, speech-to-text conversion, plagiarism checking, and course suggestions are now common in online learning [100]. These reduce the stress on lecturers and help students access content more easily. AI is fast becoming an essential part of higher education systems [21, 131].

5.2 Emerging role of AI in STEM research learning

In many African universities, especially at the postgraduate level, research learning still depends on face-to-face classroom teaching, supervision, and slow feedback. Students often wait weeks or months for corrections to their proposals or thesis chapters. This delay discourages students and extends graduation timelines. Artificial Intelligence (AI), when used as a teaching assistant, can help reduce this delay by providing rapid suggestions, explanations, and feedback. It does not replace the supervisor but adds extra support and guidance. For example, a student struggling with a literature review can use AI to generate an outline, read useful summaries, or check how their ideas flow before sharing them with their supervisor. This makes the student more confident and better able to engage in academic discussions [13, 44].

Recent studies suggest that the educational value of AI depends strongly on pedagogical design rather than technology alone. In a systematic review of 26 empirical studies, Sichterman et al. [117] found that AI-supported peer learning improved feedback

quality, collaborative engagement, metacognition, and knowledge construction when integrated with structured instructional support, personalized scaffolding, and reflective learning activities. However, the authors cautioned that poorly designed AI integration may encourage over-reliance, passive learning behaviors, and shallow engagement with academic tasks.

In STEM fields, AI can assist students and lecturers with selected research-related tasks such as literature exploration, data organization, preliminary drafting, coding assistance, and pattern identification. Nevertheless, current AI systems remain limited in their ability to handle complex methodological reasoning, experimental interpretation, theoretical originality, and context-sensitive scientific judgment without substantial human oversight. It allows them to work with big data, test experiments, and find patterns that would have taken much longer to identify manually [52]. Machine learning helps discover links between different subjects and supports the creation of new ideas. AI tools also guide students step-by-step through labs and online simulations. This supports active learning and builds students' confidence in research.

5.3 AI Tools facilitating STEM research learning

Several Artificial Intelligence-powered tools have become widely recognized in enhancing STEM research learning by supporting literature review, conceptual development, data analysis, academic writing, and publication processes [21, 131]. Five of the most relevant tools currently in use are ChatGPT, Elicit, Scite, ResearchRabbit, and Semantic Scholar AI.

- (1) ChatGPT: ChatGPT is a conversational Artificial Intelligence developed by OpenAI and designed to generate human-like responses based on user prompts. Students and researchers increasingly use it to brainstorm research questions, improve abstracts, simplify complex concepts, and generate technical content. In STEM research learning environments, ChatGPT functions as a pedagogical companion that supports writing, comprehension, inquiry-based learning, and revision processes [18, 66]. When used appropriately, it can strengthen cognitive engagement, reflective thinking, and conceptual understanding.
- (2) Elicit: Elicit is an Artificial Intelligence research assistant designed to support evidence-based reasoning and literature review processes. It uses natural language processing to identify relevant academic studies, summarise findings, extract methodological information, and organize evidence into structured formats [9, 58]. By helping users compare findings and synthesize evidence, Elicit promotes inquiry-based learning and analytical reasoning skills.
- (3) Scite: Scite is an intelligent citation analysis platform that identifies whether scientific publications support, dispute, or merely mention previous studies. The tool assists students in evaluating the strength and reliability of scientific claims by examining citation contexts and patterns [69, 90]. In STEM disciplines, where evidence quality is highly important, Scite supports critical reading, methodological awareness, and evidence appraisal skills.
- (4) ResearchRabbit: ResearchRabbit is a research discovery and visualization platform that maps relationships among authors, publications, and research topics. It allows users to organize literature collections, trace citation pathways, identify emerging research areas, and discover related studies through visual networks [16, 116]. The

platform supports exploratory learning and knowledge discovery, particularly for early-career researchers developing research interests and theoretical understanding.

- (5) **Semantic Scholar AI:** Semantic Scholar uses machine learning and artificial intelligence to improve academic search, provide smart recommendations, and generate research summaries. It also helps identify influential studies and classify citation purposes, thereby supporting efficient access to quality academic resources [38, 114]. For postgraduate students and supervisors in rapidly evolving STEM fields, Semantic Scholar enhances literature exploration beyond conventional keyword-based searching.

5.4 Criticisms and ethical concerns in AI deployment

Although Artificial Intelligence tools are becoming more useful in higher education, their adoption has raised important ethical issues and philosophical concerns. A major criticism is the risk of epistemic dependency, in which students may rely too heavily on AI outputs without thinking deeply or engaging in proper reasoning [37]. This is a serious concern in STEM research learning, where students are expected to develop critical thinking and procedural understanding. Many fear that too much automation could weaken the reflective, step-by-step nature of academic research, thereby reducing both the quality of scholarly work and the depth of academic discussions.

Recent empirical evidence supports these concerns. Noroozi et al. [91] found that many students deliberately avoided using generative AI during peer feedback activities because they believed independent completion of academic tasks promoted deeper learning and intellectual growth. The study further observed that students primarily used AI for grammar correction, tone balancing, and surface-level feedback rather than for deeper conceptual critique, raising concerns about cognitive dependence and reduced reflective engagement.

- (1) **Academic integrity:** Using AI to generate content, summarise texts, or frame research questions has led to ongoing debates about who owns such work, the line between assistance and plagiarism, and the limits of originality (Offem et al., 2025). While many institutions are developing rules to guide the use of AI, students and lecturers still face uncertainty about when and how to disclose its use. In African settings where digital skills and policies vary by place, the risk of misuse or misunderstanding is even higher.
- (2) **Data privacy and surveillance:** Most AI tools collect user data to perform better. However, people are becoming more concerned about how this data is stored, by whom it is owned, and whether third parties have access. These worries are worse in countries with weak data protection systems. Also, because many AI tools are privately owned, their inner workings are not publicly available. This can lead to hidden errors, biases, and wrong information [100].
- (3) **Educational inequality:** Students in poorly funded African universities may not have the devices, internet, or access needed to use AI tools well. In addition, AI models sometimes ignore African knowledge systems and promote Western ways of thinking. This makes it necessary to adopt AI carefully, with attention to African realities.

5.5 Current limitations of AI in research learning

Although Artificial Intelligence has great potential for STEM research and learning, its current capabilities remain limited in many ways. Although generative AI systems can simulate coherent academic responses, they lack genuine conceptual understanding, disciplinary consciousness, or independent scientific reasoning, all of which are essential for advanced academic work [53, 74]. Consequently, AI-generated suggestions in STEM research should always be subjected to expert verification, particularly in areas involving statistical interpretation, experimental validity, methodological selection, and ethical decision-making [34]. For instance, while ChatGPT can generate well-written explanations, it does not truly understand scientific processes and cannot critically determine whether an argument is methodologically sound or flawed. As a result, users must apply their own judgment when interpreting AI-generated content.

Another serious limitation is the inconsistency in AI responses. Large language models often provide answers that appear convincing but are inaccurate, fabricated, or misleading [40, 100]. This poses a significant challenge, particularly when early-career researchers rely on such information without verification. Moreover, the datasets used to train these tools may be outdated, incomplete, or biased, resulting in knowledge gaps and one-sided representations [53, 133].

AI tools also fall short in supporting the emotional, social, and collaborative dimensions of research learning. Noroozi et al., [91] argued that AI-supported learning environments still require substantial human guidance, peer interaction, and pedagogical structuring to achieve meaningful learning outcomes. Their review stressed that AI functions best when integrated into collaborative and reflective learning ecosystems rather than used as isolated technological solutions. Other studies similarly emphasize that AI cannot replace mentorship, relational depth, emotional support, or value-based supervision in higher education [59, 84, 96]. Learning to conduct research is not solely about acquiring factual knowledge and logical reasoning; it also requires encouragement, ethical guidance, and role modeling. AI cannot provide the mentorship, emotional support, or professional socialization that students need, especially in African universities where many students already experience limited access to responsive supervision and quality mentorship.

One of the most pressing issues is the digital divide. Effective use of AI assumes that students and lecturers possess digital literacy skills and have access to reliable internet connectivity and up-to-date devices [68, 101]. However, many African institutions continue to face infrastructural limitations that restrict digital access and participation. Without deliberate interventions to address these inequalities, AI adoption may worsen existing disparities in higher education [85, 112].

Furthermore, most AI tools are developed by private technology companies whose commercial interests may not always align with academic values. This raises concerns relating to the commodification of education, algorithmic bias, reduced academic autonomy, data privacy, and dependence on foreign technologies [2, 85]. To protect the values of higher education, particularly in the Global South, universities should invest in open-source technologies, context-sensitive innovations, and institutional policies that promote equity, inclusivity, transparency, and ethical use of AI in research and learning.

Current AI systems perform most effectively in structured and information-intensive tasks such as literature retrieval, language refinement, summarisation, coding support, and preliminary feedback generation [36, 133]. However, they remain substantially weaker in areas requiring originality, tacit disciplinary knowledge, experimental judgment, methodological innovation, and ethical interpretation [53]. These limitations make sustained human supervision indispensable in advanced STEM research learning.

6 AI as a pedagogical companion in STEM research learning

Artificial Intelligence is becoming a helpful academic companion in STEM research learning, especially in African universities where students often lack timely supervision and guidance. This section looks at how AI tools can support research mentoring and improve learning outcomes.

6.1 AI filling supervision gaps

In many African higher education institutions, supervision capacity for STEM research remains stretched. Supervisors juggle teaching, administration, and research, resulting in delayed feedback and minimal interaction with students (Adigun & Okebukola, 2023). AI tools offer a supplementary form of oversight by providing continuous, on-demand guidance. For instance, intelligent tutoring systems and conversational agents can answer research-related queries, simulate research dialogues, and deliver suggestions for structuring proposals or lab reports [113]. These AI companions serve as supplementary research support tools, providing preliminary guidance, formative feedback, and scaffolding for routine research tasks. However, AI systems cannot replace the disciplinary expertise, contextual judgment, ethical reasoning, and methodological decision-making required in advanced STEM supervision. Their role is therefore supportive rather than supervisory.

6.2 Personalized feedback and access to literature

AI tools offer personalized academic support that aligns with individual research needs. Platforms like Elicit and Semantic Scholar AI assist students in discovering relevant literature, summarising findings, refining research questions, comparing methodologies, and planning experimental designs. These tools provide iterative feedback on key research components such as abstracts, literature reviews, and discussions, fostering self-correction and reflective thinking. ChatGPT and emerging tools like Scraft generate feedback prompts and Socratic-style questions that help students clarify arguments and identify inconsistencies [43]. Empirical studies further show that AI-supported peer feedback systems improve the quality of feedback students give and receive, thereby enhancing writing outcomes [44]. In STEM research learning, this reduces both cognitive burden and emotional strain, especially where human supervision is limited.

6.3 Writing support and problem-solving assistance

AI applications assist with structuring academic writing, clarifying scientific concepts, and addressing technical problems [26, 54]. ChatGPT helps students organize content, interpret statistical outputs, and build logical narratives through interactive feedback and guided prompting [71]. Prompts such as “explain why my experiment design may be flawed” can generate reasoned AI responses that suggest alternative approaches or

identify conceptual gaps. Tools such as ResearchRabbit allow users to map citation networks and explore research trends, thereby supporting thematic coherence and contextual depth within literature reviews [16, 116]. Similarly, Semantic Scholar provides concise summaries, intelligent recommendations, and methodological insights that support literature exploration and synthesis [114]. These tools simulate aspects of cognitive apprenticeship by modeling expert-like reasoning and enabling exploratory learning, especially in situations where direct mentorship is limited [65].

6.4 Practical examples and case-based applications

An African example is Kwame for Science, an AI teaching assistant deployed in West Africa to support science education. Over eight months, the tool served 750 users across 32 countries, achieving 87% top-three answer accuracy in responding to students' science-related queries [10]. Although designed for secondary schools, Kwame's architecture offers insights into adapting AI for higher-education research support—particularly in under-resourced environments. Globally, tools such as AIIA (Artificial Intelligence Enabled Intelligent Assistant) personalize learning by generating adaptive quizzes, flashcards, and feedback based on user input [111]. These functions simulate on-demand mentoring, guiding students through the evaluation of literature, the formulation of hypotheses, and methodological reasoning. In addition, the AI chatbot Eva has been piloted in peer feedback systems for writing-intensive courses. Its integration improved both the quality of feedback and students' writing in an EFL context [44]. Though not STEM-specific, this demonstrates how AI companions can enhance reflective thinking and academic writing, skills crucial for success in STEM research learning.

6.5 Reflections on African realities and adaptation

Despite the promising affordances of AI, its adoption as a pedagogical companion in African higher education must consider infrastructural and cultural constraints. Internet connectivity is often unstable, electricity supply remains irregular, and many institutions lack modern hardware or access to cloud-based systems. Studies show that only a minority of African students have reliable access to digital devices, limiting their ability to engage meaningfully with AI tools [4]. Without addressing these barriers, AI may widen existing educational disparities.

Cultural relevance is equally crucial. AI systems trained on global datasets often fail to reflect local languages, metaphors, and disciplinary examples familiar to African STEM students [4]. To be effective, AI must be localized to align with regional research priorities, incorporate vernacular expressions, and reflect socio-cultural contexts. Tools like *Kwame*, developed for West African students, demonstrate the importance of culturally responsive AI in enhancing learning outcomes.

Several emerging initiatives further illustrate that AI integration is possible even within resource-constrained educational environments. For example, offline-capable and low-bandwidth AI systems are increasingly being explored to support learning in regions with unstable internet connectivity. In South Africa, mobile-compatible AI learning platforms and blended support systems have been piloted to improve access to academic support among students in underserved institutions [32]. Similarly, the Kwame for Science initiative in West Africa demonstrated that lightweight AI teaching assistants can successfully support science learning across multiple African countries

despite infrastructural limitations [10]. Some universities have also adopted hybrid implementation strategies, including shared digital laboratories, institutional AI hubs, subsidized internet access, and AI literacy workshops for students and lecturers. These approaches suggest that effective AI integration in Africa does not always depend on high-end infrastructure, but rather on context-sensitive adaptation, institutional commitment, and equitable digital support systems.

Capacity building remains a priority in Africa [4]. This means that faculty and students require training in AI literacy, not only in tool usage, but in evaluating outputs, detecting bias, and citing responsibly. Institutional policies should promote the transparent use of AI, ensure equitable access, and uphold academic integrity. Without these safeguards, AI risks uneven implementation and misuse in educational settings. Students and faculty need to work together to design AI-enhanced learning ecosystems that uphold research quality, encourage critical engagement with AI outputs, and ensure broad access. AI cannot replace human supervision; instead, it should extend and amplify it, serving as a companion that supports students during moments when “the teacher is too far.”

7 Benefits, risks, and ethical concerns

This section examines the complex implications of AI in research mentoring, structured into three subsections: Benefits, Risks, and Ethical Concerns. Each part provides a balanced analysis of how AI can either enhance or compromise academic development, particularly in higher education contexts facing technological, cultural, and regulatory shifts.

7.1 Pedagogical benefits of AI in STEM research learning

AI tools offer significant pedagogical value in STEM research learning by widening access to supervision, enabling personalized support, and enhancing student autonomy. From automated literature mapping to intelligent feedback systems, AI scaffolds research learning in ways that can improve both student experience and research outcomes. In under-resourced contexts such as African universities, AI provides consistent, on-demand academic support. Tools like ChatGPT, Elicit, and Scite deliver personalized feedback and scalable interaction, helping to bridge supervision gaps common in overcrowded or poorly funded institutions [80]. This aligns with Vygotsky’s Zone of Proximal Development, where AI can simulate some functions associated with a ‘more knowledgeable other’ by providing adaptive prompts, feedback, and scaffolding during research tasks, helping students move beyond their current capabilities through digital scaffolding.

AI also fosters inclusivity. Recent systematic evidence further suggests that AI-supported peer learning environments can strengthen metacognitive awareness, collaborative regulation, and higher-order thinking when designed around adaptive scaffolding and student-centered interaction. AI-assisted systems were particularly effective when students retained autonomy over whether and how to apply AI-generated suggestions [117]. Students with limited access to expert guidance can use AI to clarify concepts, frame research questions, and address methodological issues. For many first-generation or linguistically diverse students, AI can serve as a non-judgmental learning companion that reduces fear and encourages participation [13]. This aligns with constructivist views that emphasize student-centered environments in which students actively construct

knowledge with responsive support. Moreover, AI promotes metacognitive growth. By helping students refine arguments, critique drafts, and reflect on feedback, AI cultivates self-regulation and critical thinking. Writing assistants, for example, have improved students' argument quality, clarity, and planning strategies when used appropriately [44]. This supports cognitive apprenticeship theory, which values modeling and coaching in developing expert-like reasoning.

AI also democratises access to research knowledge. Tools like ResearchRabbit and Semantic Scholar AI allow students to trace citation patterns, explore research trends, and discover interdisciplinary connections. This exposure fosters intellectual curiosity and connects students to global scientific discourse, an important gain for African universities striving to strengthen their research cultures. Finally, AI supports supervisors and lecturers. For overstretched academic staff, AI can automate formative feedback, identify struggling students early, and offer multilingual assistance. These functions reduce workload and allow faculty to focus on high-level mentoring. Thus, AI enhances both student learning and institutional capacity for effective research supervision [63, 117].

7.2 Risks of AI in STEM research learning

Despite its benefits, AI integration in STEM research learning presents critical risks. One key concern is the risk of intellectual dependency. While AI can support inquiry, excessive reliance may hinder students' ability to reason independently. Regularly using AI to generate hypotheses, structure arguments, or paraphrase texts may bypass essential processes of critical thinking and problem-solving. Over time, this weakens the development of original research competence [54].

AI tools can also mislead students. Generative models are prone to "hallucination," the production of fabricated references, flawed summaries, or plausible but false information [37]. These risks reinforce the need for guided AI integration rather than unrestricted use. Human supervision, source-verification training, and structured AI literacy programs can help students critically evaluate AI-generated outputs rather than accepting them uncritically. Recent studies also suggest that the use of reflective and scaffolded AI reduces passive dependence and promotes metacognitive engagement [13, 117]. Novice researchers unfamiliar with disciplinary norms may struggle to detect these inaccuracies, posing risks to research quality and epistemic integrity, especially in science-based fields.

The erosion of academic rigor is another issue. AI can generate fluent but shallow drafts, encouraging surface-level engagement with academic tasks [24, 132]. Students may submit work assembled by AI with minimal reflection or scholarly effort, thereby weakening originality, critical thinking, and deep learning processes [64, 105]. This undermines academic learning and places pressure on assessment systems to evaluate authenticity, intellectual contribution, and depth of thought.

Furthermore, AI may deepen educational inequalities. Although it promises wider access to learning support, AI use depends heavily on internet availability, device quality, institutional infrastructure, and digital literacy [75]. In many African universities, infrastructural limitations restrict access to cloud-based and real-time AI systems, particularly in rural or underfunded institutions [32]. This creates disparities between digitally privileged students and those facing technological constraints.

There is also the risk of epistemic bias. Most AI models are trained predominantly on Euro-American datasets, often sidelining indigenous knowledge systems, African research priorities, and local methodologies [46, 94]. Students may therefore adopt foreign frameworks that are misaligned with their cultural and social realities, leading to the marginalization of local perspectives and indigenous scholarship [70, 79]. This promotes a subtle form of academic neocolonialism masked as global scholarship [6, 73].

Lastly, AI may disrupt the supervisor–student relationship. Students may become overly dependent on AI systems rather than seeking clarification from supervisors, potentially leading to misinterpretations of feedback and weakened scholarly dialogue [72]. Supervisors may also find it difficult to trace the origins of AI-assisted drafts, especially when AI use is undisclosed or covert [41, 70]. These developments may weaken trust, reduce the quality of mentorship, and undermine the relational dimensions of effective research supervision.

7.3 Ethical concerns in AI-supported research learning

AI tools, when introduced as pedagogical companions, have the potential to narrow access gaps by providing immediate feedback, clarifications, and adaptive suggestions [63, 82]. However, such integration must be undertaken with caution. AI lacks human reasoning, moral judgment, awareness of academic policy, and the ability to assess source credibility without direction [20, 104]. As such, its effective use in research learning requires not only digital literacy but also sound academic judgment. Students must critically evaluate AI outputs, thoughtfully revise them, and cite sources appropriately. Without this layer of human oversight, the risk of academic dishonesty, shallow reasoning, plagiarism, and uncritical copying increases [55, 108]. Hence, AI use must be guided by pedagogical principles that promote responsible engagement with machine-generated content.

The deployment of AI in research mentoring raises complex ethical issues relating to authorship, academic integrity, data privacy, surveillance, and algorithmic bias [31, 67]. In African universities where regulatory frameworks are still evolving, the uncritical adoption of AI could compromise scholarly standards. This subsection, therefore, interrogates these ethical concerns and advocates culturally responsive and ethically grounded approaches to AI use in higher education.

Plagiarism is one of the most pressing concerns. AI-generated text is often difficult to distinguish from human writing, thereby complicating authorship verification and academic integrity processes [20, 104]. When students present such content as their own, they violate established principles of scholarly honesty. Tools like ChatGPT can generate original-seeming material, but this does not exempt users from responsibilities relating to citation, authorship norms, and scholarly accountability [67, 93]. The question of authorship therefore becomes blurred: who owns AI-generated text, and should such outputs be cited, acknowledged, or treated as co-authored content? These unresolved questions have major implications for institutional policy and academic governance.

In response, many universities have begun developing policies on the use of AI in teaching and research. Some institutions permit AI use with disclosure requirements, while others prohibit it entirely [15, 89]. However, enforcement remains inconsistent, and students often receive limited guidance on acceptable AI practices. Supervisors must therefore play a proactive role in helping students distinguish between acceptable

uses such as summarisation, brainstorming, and idea generation, and unethical practices such as full-text substitution, fabricated citations, or covert paraphrasing [35, 55].

Data privacy presents another serious ethical challenge. Many AI tools collect and process user inputs, including prompts, queries, and document drafts (Dutta, [31]; [48]). Without informed consent or proper anonymization, students risk exposing their research content and intellectual property to third-party systems. This concern is particularly significant in countries with weak data protection laws or limited regulatory enforcement [51, 56]. As a result, students may unknowingly surrender ownership or control over their academic work.

AI can also be used for surveillance. Some institutions have adopted AI-driven plagiarism detectors, behavioral analytics systems, and monitoring technologies without adequately informing students [23, 42]. Such opaque surveillance practices undermine trust, weaken academic freedom, and diminish student agency. Ethical concerns become even more pronounced when surveillance technologies are deployed without transparency or clear pedagogical justification [98, 108].

Algorithmic bias is equally troubling. AI systems are trained on datasets that often contain embedded social, cultural, and linguistic biases [8, 46]. In STEM disciplines, where neutrality is frequently assumed, students may fail to recognize how AI subtly reproduces gendered, racial, and regional inequalities. These biases may shape citation recommendations, research framing, and language use, thereby steering students away from contextually relevant or indigenous scholarship [94]. This may promote a subtle form of academic neocolonialism masked as global scholarship.

To mitigate these ethical risks, universities should embed AI ethics and literacy into the curriculum. This includes training staff and students on responsible AI use, establishing clear institutional policies, and ensuring alignment with local educational values and academic goals [63, 89]. Preference should also be given to open-source AI tools that are transparent, auditable, and compliant with local data protection standards. Where possible, African universities should invest in developing homegrown AI systems that reflect indigenous knowledge systems, local languages, and cultural priorities [82, 87]. Ethical integration of AI is therefore not merely about adopting technologies, but about aligning educational innovation with principles of student agency, epistemic justice, and academic integrity.

The pedagogical companion model proposed in this paper seeks to mitigate these ethical risks by positioning AI as a supervised, transparent learning support tool rather than an autonomous content generator. Emphasis on AI literacy, disclosure practices, reflective engagement, and supervisor oversight helps maintain academic integrity while still allowing students to benefit from AI-assisted learning [63, 82].

Hybrid intelligent feedback models may also reduce ethical risks associated with unrestricted GenAI use by embedding transparency, supervisor accountability, and human verification into the feedback process [86]. Positioning AI within supervised pedagogical systems helps address concerns about plagiarism, misinformation, algorithmic bias, and epistemic dependence.

8 Reimagining the role of lecturers and institutions

The pedagogical companion approach proposed in this paper does not advocate unrestricted reliance on AI. Rather, it frames AI as a scaffolded support mechanism operating within human-supervised learning environments. By combining AI assistance with reflective pedagogy, supervisor oversight, ethical training, and institutional regulation, the model aims to address frequently identified concerns in the literature, including hallucinations, shallow learning, plagiarism, epistemic dependence, and digital inequality. As AI becomes integral to research and learning, the roles of lecturers and institutions must shift. Rather than replacing human guidance, AI should serve as a co-supervisor, complementing mentorship. This section discusses changing supervisory roles, the need for staff training, and strategies for institutional integration. It also highlights implications for curriculum, leadership, and digital infrastructure to ensure AI supports core academic values.

8.1 AI as a co-supervisor, not a replacement

AI tools increasingly act as co-supervisors by providing students with immediate feedback, research suggestions, and language support. Tools such as ChatGPT, Elicit, Scite, and ResearchRabbit assist with formulating hypotheses, exploring scholarly literature, and structuring reports. These tools allow students to work more consistently, especially when human supervisors are unavailable or overburdened. However, AI lacks emotional intelligence, cultural insight, or a nuanced understanding of disciplinary norms. Therefore, institutions must emphasize clearly that AI is an assistant rather than a replacement. Roles must be defined such that AI augments the student's research process without undermining the relational and moral responsibilities of human mentorship. By positioning AI as a supplementary rather than autonomous research support system, this model attempts to balance accessibility with scholarly rigor. Students receive immediate support while remaining accountable to human supervisors for methodological decisions, ethical judgment, and disciplinary interpretation.

8.2 Pedagogical principles for hybrid human–AI research support

Effective AI integration in STEM research learning should be based on complementarity rather than substitution. Banihashem et al. [7] argued that hybrid intelligent feedback systems work best when AI contributes speed, scalability, and routine analytical support while human supervisors contribute contextual understanding, disciplinary judgment, emotional sensitivity, and ethical reasoning. In STEM supervision, AI may assist with literature searches, language refinement, coding support, and preliminary feedback, whereas human mentors remain central in methodological reasoning, experimental interpretation, and scholarly decision-making. The framework also emphasizes iterative refinement, where AI-generated feedback is continuously reviewed, questioned, and enriched through human interaction. Rather than passively accepting machine-generated responses, students should critically evaluate AI suggestions through dialogue with supervisors and peers. Such iterative engagement may strengthen metacognitive awareness and reflective learning while reducing overdependence on AI-generated outputs.

Banihashem et al. [7] further proposed the principle of shared agency, in which students actively participate in determining how AI-generated support is used within the learning process. This principle is especially important in STEM research learning

because students must develop independent scientific reasoning rather than merely implementing automated recommendations. AI should therefore function as a negotiable support tool rather than an unquestioned authority.

Although AI systems can generate timely and personalized feedback, they lack genuine empathy, emotional awareness, and lived disciplinary experience. Human supervisors, therefore, remain essential for motivating students, managing research anxiety, nurturing scholarly identity, and supporting emotional resilience during demanding research processes. Hybrid models become most effective when AI efficiency is balanced with sustained human mentorship and relational support.

The framework also supports adaptive human oversight, where the level of AI involvement varies according to task complexity and student needs. Routine and structured tasks may involve greater AI assistance, whereas complex methodological reasoning, ethical dilemmas, and interpretive decision-making require stronger human supervision. Such adaptive integration may help preserve academic rigor while still benefiting from AI-supported efficiency.

8.3 Redefining the role of supervisors

As AI takes on routine tasks in research and learning, supervisors must evolve into intellectual mentors, ethical guides, and contextual interpreters. Supervisors should shift from delivering information to fostering critical thinking, situating students' work within local and global scholarship, and guiding them through the emotional and ethical complexities of research. Co-mentorship frameworks, in which faculty collaborate with AI tools and peer mentors, can more equitably distribute the guidance load [7]. This paradigm encourages supervisors to focus on higher-order skills such as developing publication strategies, peer review in STEM research, and critical appraisal of AI-generated arguments.

8.4 Professional development for faculty on AI

Effective integration of AI into research pedagogy depends on lecturers' understanding both the affordances and limitations of these tools. Faculty development should go beyond tutorial sessions to include ethical case studies, prompt engineering exercises, and collaborative AI evaluation panels. Continuous professional development programs, peer-led workshops, and interdisciplinary AI literacy modules can ensure lecturers gain competence and confidence. Faculty must be able to critically assess AI outputs, detect hallucinations or biases, and guide students in responsible AI use. Such training is particularly important in reducing risks associated with hallucinated references, algorithmic bias, and uncritical dependence on AI-generated content.

8.5 Institutional policies for integrating AI meaningfully

Institutions must establish comprehensive policies to govern the use of AI in research and learning. These policies should address acceptable AI usage, disclosure of AI assistance, data privacy protocols, co-authorship implications, and quality assurance standards. Such guidelines must evolve in tandem with technological advancements and align with pedagogical ethics. Multidisciplinary policy committees that include faculty, legal experts, librarians, and student representatives can ensure policies remain relevant, inclusive, and enforceable. These frameworks help foster transparency, safeguard

academic integrity, and define the role of AI in the research ecosystem. These institutional safeguards are essential for addressing frequently reported concerns in the literature, including plagiarism, authorship ambiguity, data privacy risks, algorithmic opacity, and unequal access to AI technologies.

8.6 Curriculum design and pedagogical innovation

Curricula must be redesigned to integrate AI-supported research practice, ethical reasoning, and digital reflexivity. Modules should include AI-based inquiry tasks, reflective assignments on the use of AI, and collaborative research projects in which students compare human and machine contributions. Pedagogical designs such as AI-supplemented lectures, formative AI assessments, and group discussions centered on prompt evaluation foster critical engagement with AI rather than passive use. This approach nurtures not only STEM research skills but also meta-cognitive awareness and digital fluency among students. Embedding AI literacy into STEM curricula may help students distinguish between the use of AI and overreliance on it [55, 63]. Activities that require students to critique AI-generated responses, compare human and machine reasoning, and verify AI-supported claims may strengthen critical thinking and reduce passive acceptance of generated content. Curriculum design in AI-supported STEM education should move beyond the adoption of technical tools toward developing critical AI literacy. Students should be trained to verify AI-generated information, question automated feedback, identify hallucinated references, and compare machine-generated reasoning with disciplinary standards. Activities involving reflective critique of AI outputs may strengthen analytical thinking while reducing passive dependence on generative systems.

8.7 Leadership, governance, and change management

Successfully reimagining institutional roles in an AI-integrated environment requires strong leadership and strategic governance. Academic leaders should establish AI integration committees, invest in appropriate IT infrastructure, and align AI initiatives with national higher education objectives. Effective governance includes setting priorities, monitoring impact, and managing change sensitively within institutional culture. Leadership must also mediate tensions between innovation and tradition, ensuring that AI adoption remains inclusive, ethical, and context-responsive.

8.8 Library services and information literacy

Academic libraries occupy a strategic position in AI-augmented research learning. Librarians must become proficient in AI tools such as semantic search engines, citation analysis platforms, and evidence visualization systems. They should teach students how to verify AI-generated content, trace sources, and avoid biased or outdated information. Furthermore, libraries can collaborate with faculty to develop curricula that integrate AI-based literature reviews and research data management. By doing so, libraries ensure that AI becomes a partner in scholarly exploration rather than a black box of knowledge production.

Drawing from hybrid intelligent feedback frameworks, this paper argues that effective AI integration in STEM research learning should prioritize complementarity, shared agency, iterative refinement, adaptive supervision, and reflective engagement. Rather than replacing supervisors, AI systems should function within pedagogically guided

human-AI partnerships that preserve critical thinking, emotional support, disciplinary judgment, and ethical accountability while expanding access to timely academic assistance.

9 Future directions for research and policy

As AI becomes more central in higher education, its impact on teaching, ethics, and institutional practice must be carefully monitored. In STEM research learning, especially in African universities, future research and policy must go beyond reacting to challenges. They should guide fair and locally relevant innovations. This section discusses three key priorities: areas for further research, the need for contextual theories, and important policy directions for institutions and regulators.

9.1 Areas for future empirical studies

There is a pressing need for empirical research on how AI tools affect STEM research learning in African universities. The current discourse is mostly conceptual, with few studies providing measurable outcomes. Future studies should explore the cognitive, behavioral, emotional, and epistemic effects of using AI tools such as ChatGPT, Elicit, and ResearchRabbit in research tasks, including topic selection, literature review, and academic writing. A key area is how AI affects students' autonomy in learning. There is little evidence on its impact on self-regulated learning, critical thinking, and motivation. Longitudinal studies can help track behavioral changes in AI users versus non-users. Research is also needed to assess the role of AI in promoting or reducing originality and creativity in postgraduate research.

Another gap is the varying impact of AI across disciplines and study levels. Comparative studies between STEM and non-STEM fields could reveal discipline-specific patterns. Similarly, analyzing AI engagement among undergraduates, master's, and PhD students could inform tailored instructional and supervisory practices. Supervisors' experiences with AI use in research mentoring also remain underexplored. Studies should examine their trust in AI-generated content, methods for guiding responsible use, and the challenge of maintaining academic standards in AI-assisted environments. Mixed-methods research involving surveys, focus groups, and classroom observations can provide rich insights into these pedagogical shifts. Finally, quantitative research should evaluate the influence of AI on the quality of research outputs, such as coherence, citation accuracy, and publication outcomes. This is particularly important for doctoral theses and journal articles where AI use may not be visible but can shape the final work. Findings from such studies can inform institutional guidelines and quality assurance frameworks.

9.2 Need for contextualized frameworks

Existing models for AI integration in higher education mostly originate from Western settings and often fail to capture the technological, pedagogical, and socio-cultural realities of African universities. There is an urgent need for conceptual frameworks grounded in African contexts to explain how AI tools interact with human users and institutional systems in resource-limited environments. Such frameworks must reflect disparities in infrastructure, internet access, and device availability. In many African universities, access to AI is constrained by unreliable electricity, limited bandwidth, and financial

constraints. These challenges affect how students and lecturers engage with AI, and must be factored into any relevant theoretical model. Sociocultural influences also shape AI usage. Pedagogical beliefs, student attitudes towards machine-generated content, and institutional trust in digital platforms vary widely.

Cultural norms around originality, authority, and learning hierarchies matter. In settings where students rely heavily on supervisors, AI may be used as a substitute rather than as a collaborative tool. A meaningful framework must account for these dynamics. Language and epistemology pose another concern. Most AI tools are trained on English and Western-centric databases that rarely include African perspectives, local theories, or indigenous problems. New models should examine whether AI reinforces epistemic exclusion or creates openings for decolonizing academic knowledge. The impact of AI on not just research skills but also epistemic legitimacy must be interrogated. Finally, power relations in AI use must be addressed. Who decides how AI is accessed? Who defines responsible use? What happens when AI outputs challenge supervisors' feedback or institutional norms? Theoretical models must include dimensions of power, access, and legitimacy. Without this, AI risks reinforcing dependency rather than advancing self-determined academic growth in African settings [73, 94].

9.3 Policy recommendations for universities and higher education bodies in Africa

Artificial intelligence can support rather than disrupt STEM research learning in African universities, but this depends on sound policy decisions. Institutions and national bodies must work together to guide their use in ways that are responsible, fair, and locally relevant. Policies should also require transparent disclosure of AI assistance in research writing and encourage verification protocols for AI-generated references, summaries, and analytical outputs.

1. Universities need clear guidelines on how AI should be used in research and learning. These should cover what is acceptable, what must be disclosed, how to cite AI-generated content, and the penalties for misuse. While policies should allow room for technological changes, they must still uphold academic integrity. Input from lecturers, students, IT units, and legal staff is important to make such policies widely acceptable and practical.
2. Bodies such as the National Universities Commission (NUC) in Nigeria and the Association of African Universities (AAU) should lead in setting rules that suit African realities. These guidelines must not simply copy global models. They should support equity by helping weaker institutions improve infrastructure and gain access to open-source AI tools that reduce costs and close digital gaps.
3. Postgraduate research training should include ethics education on how to use AI responsibly. This training should cover data privacy, bias in AI systems, prompt design, and other basic digital skills. It should also teach values drawn from African traditions and collective accountability systems. This will help students understand both the benefits and the risks of using AI tools.
4. University authorities and education ministries must fund training to help lecturers use AI tools effectively in research supervision and teaching. Those who adopt such tools meaningfully should receive recognition, research funding, or career advancement points. This will encourage more lecturers to engage with AI confidently.

5. African universities should partner to reduce waste and share learning. Joint platforms, research centers, and think tanks can help universities co-develop AI tools that are tailored to African languages, values, and scientific needs. This will make universities active participants in AI development rather than passive users of imported tools.
6. Every university should track how AI is affecting learning, supervision, and research quality. Annual reports should go beyond technical performance. They should assess how AI tools influence student identity, ethical behaviour, and academic standards. The results can guide future policy reviews and identify where more training or funding is needed.

10 Conclusion

This paper examined the changing role of artificial intelligence as a learning companion in STEM research across African universities. Drawing on four learning theories, it argued that AI can help students move from dependence to independence, especially when handling complex academic tasks. The discussion focused on the philosophical tensions, ethical concerns, and teaching opportunities presented by tools such as ChatGPT and ResearchRabbit. Although AI can support writing and literature engagement, careless use may weaken students' thinking and promote over-reliance. Its benefits depend on how it is applied. Responsible use, relevant practices, and inclusive rules are needed to ensure AI strengthens learning without weakening human supervision or local ways of thinking [7].

The guiding metaphor of this paper, *"I have many questions to ask, but the teacher is too far,"* speaks to the reality of students struggling to learn research in environments where access to supervision is limited, infrastructure is weak, and support is often delayed. In such cases, AI can help reduce the distance between students and their teachers. This does not mean replacing lecturers, but supporting them by providing smart, culturally aware, and ethical tools.

When used properly, AI can help students bridge knowledge gaps, guide their thinking, and allow them to explore ideas more freely. At the same time, it must not take away the human and cultural value of mentorship. As African universities face overcrowded classrooms, limited resources, and international academic expectations, the use of AI in STEM research learning is becoming increasingly necessary. Nevertheless, such use must align with African values, ethical norms, and policies that include everyone. Changes in teaching, infrastructure, and institutional management must reflect a vision that puts fairness and local needs first. This is the only way AI can truly support students' academic journeys while still respecting their identity, culture, and educational goals.

Author contributions

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Ethics approval and consent to participate

This study did not involve human participants or animals and therefore did not require ethics approval.

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