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# Enhancing Learner Engagement through Artificial Intelligence Integration in Ugandan Rural Primary Schools' Science Classroom Instructional Practices

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## ABSTRACT

**Purpose:** This study examined the integration of Artificial Intelligence (AI) tools in science education in selected primary schools in Bududa District, Uganda. It focused on implications for teacher education and professional development within resource-limited contexts. Guided by constructivist and cognitive load theories, the research investigated how AI affects learner engagement, instructional practices, and classroom dynamics.

**Methodology:** A mixed-methods approach was used, incorporating pupil interviews, teacher questionnaires, and classroom observations. This provided a comprehensive understanding of how AI tools were being adopted and experienced in real classroom settings.

**Findings:** Artificial Intelligence (AI) tools such as educational simulations and interactive quizzes improved learner motivation, collaboration, and conceptual understanding. However, implementation was inconsistent due to inadequate digital infrastructure and limited teacher training. While many teachers expressed a willingness to adopt AI, they lacked the necessary digital skills and support systems to use these tools effectively.

**Unique Contribution to Theory, Practice and Policy:** Theoretically, the study links AI-enhanced learning to constructivist and cognitive load principles in low-resource environments. In practice, it highlights the need for teacher education programs that develop AI literacy, pedagogical adaptability, and context-sensitive strategies. On a policy level, the study recommends revising teacher training curricula to include AI integration, alongside increased investment in digital infrastructure and professional development. These measures are critical for advancing equitable and effective science education in rural Ugandan schools.

**Keywords:** *Artificial Intelligence, Science Education, Learner Engagement, Teacher Training, Educational Innovation*

## 1.0. Introduction

### 1.1 Background

Science education is pivotal to technological advancement, especially in the 21st century, and remains vital for Uganda's development (Nabushawo et al., 2019; MOES, 2020a). However, rural areas like Bududa District face serious challenges including overcrowded classrooms, inadequate resources, and a heavy reliance on rote learning methods (UNESCO, 2021a; Karamagi & Nabbosa, 2018a). These systemic issues undermine learners' comprehension and ability to apply scientific concepts (Ssempala, 2017; Mwanja et al., 2019). Observations revealed that the "chalk-and-talk" approach dominates science classrooms, limiting inquiry, creativity, and critical thinking—an issue also documented in regional studies (Mubiru & Nalubega, 2017; Mugagga et al., 2022; Kintu, Zhu & Kagambe, 2017; Nambi et al., 2016).

Artificial Intelligence (AI), defined as machines mimicking human intelligence, is increasingly being used in education through intelligent tutoring systems, simulations, chatbots, and virtual labs (Luckin et al., 2016; Holmes et al., 2019). These tools offer immediate feedback, personalize learning, and make abstract concepts more accessible (Chen et al., 2020; Zawacki-Richter et al., 2019; Yin et al., 2020). Globally, over 36% of education systems have adopted some form of AI, with countries in Asia and Europe investing heavily in AI-enhanced learning (UNESCO, 2021a; Tuomi, 2018; Becker et al., 2018). Africa is progressing more slowly, though initiatives in Rwanda and Kenya show encouraging outcomes, with 18 countries now exploring AI integration (Wambugu et al., 2019; Ndung'u & Wanjiru, 2020a).

In Uganda, despite policy support such as the ICT in Education Policy (2019), AI usage in classrooms, particularly rural ones, is still minimal (Munene, 2021a; Okello et al., 2023). This digital divide exacerbates existing educational inequalities. AI tools have shown to improve academic performance and engagement through adaptive learning and learner-centered pedagogy (Tuomi, 2018; Becker et al., 2018; Li et al., 2019). In resource-limited settings, tools like virtual labs bridge infrastructure gaps by offering experiential, interactive learning (Akinola et al., 2022; VanLehn, 2016; Holmes et al., 2018). Countries like Rwanda and Kenya have demonstrated the scalability of AI in improving learner outcomes when coupled with teacher training and policy support (Mwangi et al., 2023; Makokha & Mutisya, 2016).

Given Bududa's limited exposure to such innovations, this study aimed to assess the feasibility and impact of AI tools on science education within this rural context. The findings are intended to inform inclusive, evidence-based interventions for AI integration in Uganda's rural schools.

### 1.2 Problem Statement

Despite the advent of AI tools in to rural Ugandan primary schools, learner achievement in science remains low, particularly in rural districts like Bududa (MOES, 2019; Uwezo Uganda, 2020). Persistent underperformance is linked to outdated, teacher-centered pedagogies that prioritize rote learning over conceptual understanding, resulting in disengaged learners and poor scientific literacy (Karamagi & Nabbosa, 2018b; Nakabugo et al., 2022). Traditional "chalk-and-talk" methods continue to dominate classrooms, often due to limited resources and lack of teacher training in modern instructional strategies (Musoke, 2021; Namyalo & Okello, 2023). Observations from Bududa revealed minimal use of digital tools and learner interaction, underscoring systemic gaps in pedagogy.

Globally, AI technologies are transforming education by enabling personalized learning, adaptive feedback, and interactive content (Zawacki-Richter et al., 2019; Wang et al., 2021; Chen et al., 2020). However, evidence of their effectiveness in low-resource, rural African settings remains scarce (Holmes et al., 2019; Akinola et al., 2022). Specifically, there is limited knowledge of how AI integration influences learner engagement, academic achievement, and classroom dynamics in rural Ugandan primary school science classrooms. Additionally, critical challenges, ranging from infrastructure insufficiencies to teacher preparedness, need to be understood to inform sustainable AI acceptance strategies. This study sought to address this gap by investigating the role of AI in transforming Science instruction and learner achievement in Bududa's primary schools, with the aim of providing localized insights to inform teacher education and instructional innovation in similar contexts.

### 1.3 Objectives of the Study

The study was guided by the following objectives which informed the selection of tools, methods, and analytical strategies used throughout the research process.

1. To assess the effect of AI tools on the academic performance of primary school pupils in science.
2. To examine the level of learner engagement with AI-based science tools in classroom settings.
3. To explore how the use of AI transforms science pedagogy, particularly the role of the teacher and classroom dynamics.
4. To identify challenges associated with the integration of AI in science instruction in resource-limited primary schools.

### 1.4 Rationale

The integration of AI in education supports Uganda's National Development Plan III and the MoES ICT in Education Policy, which emphasize using digital technologies to enhance teaching, learning, and equity (MOES, 2020b; NPA, 2020). This is also in line with Target 4.1 of the Sustainable Development Goal (SDGS 4) on ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all by 2030. (SDG, 2015; United Nations Educational, Scientific and Cultural Organization- UNESCO 2015**)**. These frameworks view technology as a tool to improve pedagogy and reduce disparities, especially in underserved areas.

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AI enables personalized instruction tailored to individual learner needs which is an essential feature in Ugandan classrooms marked by high learner-to-teacher ratios and diverse learning profiles (Karamagi & Nabbosa, 2018b; Okello et al., 2023). By adjusting content difficulty and feedback, AI supports inclusive, learner-centered education (Chen et al., 2020; Wang et al., 2018).

Classroom observations showed that AI simulations increased learner engagement and teacher enthusiasm, aligning with studies on AI's role in fostering pedagogical innovation (Mwangi et al., 2023; Bayo & Kamya, 2022). Research also highlights AI's potential to build learner autonomy and ensure quality education across contexts (Zawacki-Richter et al., 2019; Woolf, 2021; Luckin et al., 2016; Ndung'u & Wanjiru, 2020b).

This study contributes empirical, context-specific insights to inform national policy, teacher education, and the broader use of AI in Sub-Saharan Africa (Holmes et al., 2019; Akinola et al., 2022).

## 2. Literature Review

### 2.1. The Impact of AI Tools on Academic Performance in Science Education

Artificial Intelligence has significantly influenced academic achievement across multiple educational settings. Studies consistently show that AI-enhanced platforms improve learning outcomes by delivering personalized instruction, formative feedback, and scaffolded learning experiences (Chen et al., 2020; Zawacki-Richter et al., 2019). In a meta-analysis covering 80 studies, Singhal et al. (2024) found an average performance improvement of 0.35 standard deviations where AI was integrated, reinforcing earlier findings by Kulik and Fletcher (2016).

In science education, AI technologies such as virtual labs, simulations, and adaptive quizzes allow learners to interact with content actively, fostering deeper understanding of complex concepts (Munene, 2021c; Johnson et al., 2023). A study by Ramirez and Lee (2024a) showed notable improvements in physics and biology performance among pupils using AI-based tools compared to those using conventional instruction. Reyes et al. (2025) further observed that learners who used AI-driven platforms in STEM subjects showed higher test scores and longer retention rates.

These tools are particularly impactful in under-resourced areas. Ochieng et al. (2024) and Kato and Njeri (2025a) found that AI-supported learning in Kenyan and Ugandan rural schools led to academic gains despite infrastructural limitations, suggesting scalability in similar contexts like Bududa District. Moreover, Ibrahim et al. (2023) emphasized the importance of aligning AI platforms with local curricula, which directly impacts learner performance and curriculum fidelity. By leveraging AI's capabilities, Uganda can promote inclusive education and provide equal opportunities for all learners to achieve especially in science.

### 2.2. AI and Learner Engagement in the Science Classroom

AI technologies support learner engagement through interactivity, real-time feedback, and personalized learning pathways. Chatbots and Intelligent Tutoring Systems (ITS) stimulate learner curiosity and guide inquiry-based learning (Patel et al., 2023; Tan & Xu, 2023a). Learner motivation is boosted when AI tools adjust to individual pace and difficulty level, preventing both boredom and frustration (Zhang & Lee, 2024a; Chen et al., 2023). Learning engagement and learning outcomes can affect learners' motivation to learn (Hung et al., 2019).

Studies such as Andersson et al. (2024) and Smith and Kumar (2024) found that AI fosters collaboration, allowing learners to work in peer-assisted environments facilitated by AI prompts. This enhances classroom participation and builds a sense of agency among learners. In Ugandan contexts, Namyalo and Okello (2023) observed that pupils using basic AI simulations displayed heightened interest and participation in science lessons.

The use of AI also contributes to inclusive learning, as adaptive tools accommodate learners with different abilities and learning preferences (Nguyen & Brown, 2023b). Research by Yoon and Kwon (2025a) demonstrated that AI-enabled analytics empower teachers to identify disengaged learners early, enabling timely interventions. These findings support the current study's focus on AI's effect on learner engagement in rural Ugandan settings.

### 2.3. Transforming Pedagogy: AI's Role in Shaping Teaching Practices

AI integration is reshaping science pedagogy by shifting the teacher's role from knowledge transmitter to learning facilitator. According to Holmes et al. (2019), teachers in AI-enabled classrooms serve as guides, focusing on personalized support and feedback rather than rote instruction. This shift is especially critical in science, where hands-on engagement enhances understanding. Virtual labs and simulations enable experiential learning without the risks or costs associated with physical experiments (Johnson et al., 2023; Ochieng et al., 2024).

However, teacher readiness is crucial. Research by Okello and Mbabazi (2025) in Uganda shows that lack of AI training hampers effective implementation. In contrast, pilot programs in Rwanda and Kenya, where teachers received targeted digital pedagogy training, demonstrated marked improvements in instructional quality and learner outcomes (Tadesse & Muluneh, 2024b; Owusu et al., 2023). These findings support the need for robust teacher development in integrating AI effectively.

### 2.4. Barriers and Challenges to AI Integration in Resource-Limited Schools

AI adoption in Sub-Saharan Africa faces critical challenges including infrastructure deficits, digital illiteracy, and lack of policy support. UNESCO (2023a) highlights that in rural areas, frequent power outages and limited internet access hinder the use of AI tools. Bududa District exemplifies this reality, where many schools lack electricity and rely on outdated teaching aids. Adeyemi et al. (2024) report that teacher digital competence remains low, often due to inadequate training and limited exposure to educational technologies. A Ugandan study by Namyalo and Okello (2023) found that teachers were unfamiliar with even basic AI tools, creating a barrier to adoption despite their willingness to innovate.

Nevertheless, localized and low-cost AI solutions, tailored to rural contexts, have shown promise. Mumo and Otieno (2024a) documented successful AI pilots using offline adaptive learning software in rural Kenya. Similarly, Adebe and Wondimu (2025a) found that community involvement and localized content creation enhanced adoption in Ethiopian schools.

Policy responses are beginning to address these issues. The African Union (2025a) and MOES Uganda (2024) have prioritized digital transformation in their education sector plans, emphasizing infrastructure, teacher training, and content localization. These steps are essential for sustainable AI integration in low-resource environments like Bududa.

**2.5 Theoretical and Conceptual Framework**

This study is guided by two complementary theoretical frameworks: Constructivist Learning Theory and Cognitive Load Theory, which together inform the exploration of Artificial Intelligence (AI) integration in primary science education particularly in relation to learner engagement, academic performance, pedagogical transformation, and implementation challenges. This is diagrammatically represented in the figure 1 below.

Constructivist Learning Theory, rooted in the works of Vygotsky (1978) and Piaget (1952), emphasizes active learning through social interaction, inquiry, and exploration. This theory aligns with AI tools that support hands-on, learner-centered instruction through simulations, adaptive modules, and intelligent tutoring systems (Jonassen, 1999; Tan & Xu, 2023). In this study, Constructivism informed Objectives 2 and 3 by explaining how AI promotes learner engagement and reshapes pedagogy. Observational and interview data showed increased curiosity, participation, and peer interaction among pupils using AI (Patel et al., 2023; Andersson et al., 2024). Teachers also shifted from traditional roles to facilitators of learning, a transformation observed in Ugandan classrooms using even basic AI tools (Holmes et al., 2019; Namyalo & Okello, 2023; Okello & Mbabazi, 2025).

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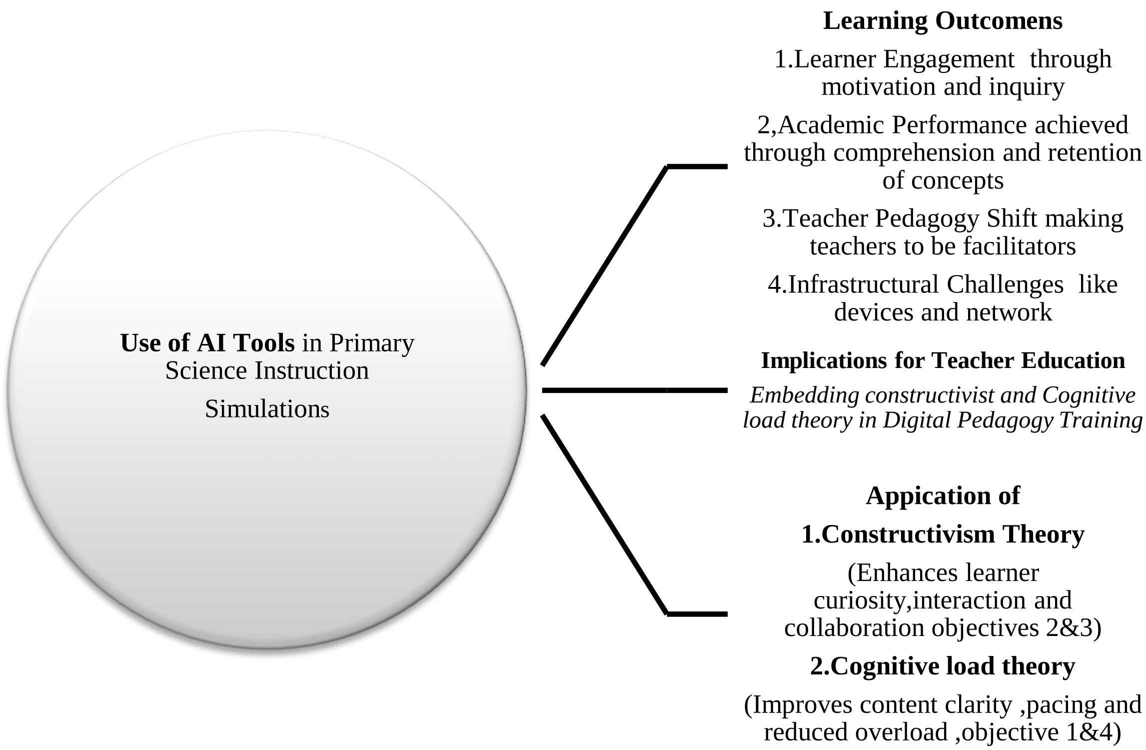


*Figure 1: Conceptual Framework*

***Source: (Vygot sky,1978 &Piaget 1952)***

Cognitive Load Theory (Sweller, 1988) focuses on optimizing learning by managing intrinsic, extraneous, and germane cognitive loads. AI tools support this by simplifying complex content, offering timely feedback, and using multimedia to enhance clarity (Paas et al., 2003; Zhang & Lee, 2024). CLT directly informed Objective 1 by explaining how AI improves academic performance through reduced extraneous load and increased focus (Chen et al., 2023; Yoon & Kwon, 2025). It also supported Objective 4 by highlighting how infrastructure gaps—like poor connectivity or device shortages—elevate extraneous cognitive load, impairing comprehension and sustained engagement (Paas et al., 2024).

Together, these theories offer a complementary lens: Constructivism addresses “how” AI fosters engagement, collaboration, and pedagogical transformation, while Cognitive Load Theory explains “why” AI affects performance by managing learners’ cognitive resources. Their joint application provides a more holistic understanding of the relationship between “AI integration (independent variable” and “learner engagement and academic performance (dependent variables)”, as well as “teacher practice and infrastructural constraints (moderating variables)”. While Constructivism is sometimes criticized for assuming all learners benefit equally from open-ended tasks, and CLT for being too focused on cognitive efficiency, their combined use balances motivational, social, and cognitive dimensions of learning. Therefore, integrating both theories

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into teacher education programs in Uganda is essential to develop pedagogically sound and technologically effective classroom practices (Adeyemi et al., 2024; Tadesse & Muluneh, 2024b).

## 3. Methodology

The study employed mixed-methods, quasi-experimental design in Bududa District, involving 30 pupils (P5 and P6) and 9 science teachers across 3 schools (two rural, one urban). Quantitative data were collected through pre- and post-tests measuring scientific knowledge in energy, matter, the environment, and the human body. AI usage logs documented frequency and duration of interaction with tools such as adaptive modules, virtual labs, and chatbots. Classroom observations assessed the integration of AI and pupil engagement. Qualitative data from interviews and focus groups enriched understanding of experiences and challenges in the learning and teaching of science with focus to use of artificial intelligence. Quantitative data were analyzed using SPSS, while qualitative data were coded and thematically analyzed with NVivo. The researcher maintained reflective journal notes throughout.

## 4. Data Presentation and Discussion

### 4.1 The Impact of AI Tools on Academic Performance

**Table 1: Pupils' Responses on the Impact of AI on Academic Performance**

| Theme | Common Response | Frequency | Percentage (%) |
|---|---|---|---|
| **Acknowledgement on the role of AI tools in understanding scientific concepts** | Yes, especially with diagrams and animations | 24 | 80% |
| | No, sometimes it is hard to follow | 6 | 20% |
| **Difficulty level of topics in using AI tools** | Easy: Human body, electricity, weather; Hard: magnetism, chemical changes | N/A | N/A |

***Source: Primary Data***

According to Table 1, 80% of pupils reported that AI tools improved their understanding of scientific concepts, especially through animations and simulations. Comments like, "I like when the computer shows how the heart pumps blood," support Constructivist Learning Theory, which emphasizes interactive and visual learning (Jonassen, 1999). However, 20% found some AI tools difficult to follow, likely due to cognitive overload. As Sweller's Cognitive Load Theory explains, overly complex or poorly scaffolded content can overwhelm working memory (Sweller, 1988; Paas et al., 2003). Pupils found AI helpful in topics like human biology, electricity, and weather, but still struggled with abstract subjects like magnetism and chemical changes highlighting the need for pedagogically aligned content.

**Teachers' Perceptions of AI's Impact on Academic Performance**

Teacher responses reinforced AI's positive impact: 55.6% agreed and 33.3% strongly agreed that AI enhances academic performance, with only 11.1% moderately agreeing. Regarding curriculum alignment, 55.6% agreed, and 11.1% strongly agreed, but 22.2% were neutral and 11.1% disagreed suggesting some AI content may not align with national curriculum goals, as Ibrahim et al. (2023) also found. Additionally, 55.6% agreed and 11.1% strongly agreed that AI feedback supports teaching strategies, though 33.3% remained neutral possibly due to limited training in using AI analytics effectively.

**Classroom Observations: Usage and Curriculum Alignment**

Out of nine observed science classes, five (56%) used AI tools such as simulations and educational videos, often via teachers' smartphones due to infrastructure limitations. These practices align with pupil and teacher reports, confirming both the value and constraints of AI integration in rural classrooms.

**Table 2: Observations on the Impact of AI Tools on Academic Performance**

| Observation Item | Observed (✓) | Not Observed (✗) | Frequency (✓) | Percentage (%) |
|---|---|---|---|---|
| **AI tools are used to teach or assess science content** | ✓ | ✗ | 5 | 56% |
| **AI tools are aligned with the topic or curriculum** | ✓ | ✗ | 4 | 44% |

**Source: Primary Data**

While over half of the observed classes used AI tools, only 44% showed clear alignment with the science curriculum; the rest used content that, though informative, lacked connection to specific learning objectives. According to Cognitive Load Theory (Sweller, 1988), this misalignment can hinder learners' ability to form coherent schemas, affecting long-term understanding. Infrastructure challenges, like the lack of projectors or computer labs, often led to passive viewing of demonstrations, limiting active learning as emphasized by Constructivist Theory. Despite these challenges, studies by Singhal et al. (2024), Ramirez and Lee (2024b), and others (Ochieng et al., 2024; Kato & Njeri, 2025a) support the positive impact of AI on academic performance, even in under-resourced settings. The findings show that learners find AI-enhanced visuals and simulations more engaging, and teachers acknowledge AI's value in improving performance and feedback. However, concerns remain regarding curriculum alignment and training. Generally, the study confirms that AI has strong potential to improve science learning outcomes when properly integrated, supported, and made accessible.

**4.2 Artificial Intelligence and Learner Engagement in the Science Classroom**

**Table 3: Pupils' Responses on Learners' Engagement with AI**

| Theme | Response | Frequency | Percentage (%) |
|---|---|---|---|
| **Thoughts of learners in interacting with AI tools** | Excited and more interested | 26 | 86.7% |
| | Bored or confused | 4 | 13.3% |
| **Mode of learning** | In groups | 18 | 60% |
| | Alone | 12 | 40% |
| **Acceptance on AI in feedback provision** | Yes, it shows the correct answer or hints | 20 | 66.7% |
| | No or not sure | 10 | 33.3% |
| **Acceptance on continued use of AI tools** | Yes | 25 | 83.3% |
| | No | 5 | 16.7% |

**Source: Primary Data**

Learner engagement plays a crucial role in academic success, especially in science education where curiosity, interaction, and visual aids enhance understanding. This study examined how AI tools impact engagement in rural science classrooms, with findings supported by literature and grounded in educational theories. A large majority (86.7%) of learners reported feeling more excited and interested when using AI tools, expressing preferences for interactive visuals over text findings consistent with Patel et al. (2023) and Tan & Xu (2023b), who highlight AI's role in boosting motivation through visualization and personalization. These outcomes align with Constructivist Learning Theory (Piaget & Vygotsky), which emphasizes learning through active engagement. Regarding collaboration, 60% of learners preferred group work, citing peer support, while 40% favored individual learning to avoid distractions indicating the need for flexible AI applications, as supported by Smith & Kumar (2024) and Andersson et al. (2024). Additionally, 66.7% valued AI-generated feedback, which, according to Cognitive Load Theory (Sweller, 1988), helps reduce cognitive overload echoed by Zhang & Lee (2024b) and Chen et al. (2023). Lastly, 83.3% of pupils expressed a desire to continue using AI in science lessons, reinforcing Namyalo & Okello's (2023) findings that even basic AI tools can boost motivation in Ugandan classrooms.

**Teacher Perspectives on Learner Engagement**

Teacher responses closely aligned with pupil feedback, showing strong support for AI's role in enhancing engagement. A total of 66.7% of teachers agreed and 33.3% strongly agreed that AI tools improve learner interest and participation, with no disagreement reported. Similarly, 66.7% observed increased collaboration among pupils during AI-supported lessons, while 33.3% were neutral. Regarding inclusivity, 55.6% agreed and 33.3% strongly agreed that AI supports learners of different abilities, with only 11.1% neutral. These findings support Nguyen & Brown (2023b) and Yoon & Kwon (2025b), who found that adaptive AI tools enhance engagement for both struggling and advanced learners, reinforcing inclusive teaching practices.

**Table 4: Researcher's Observations on Learner Engagement**

| Observation Item | Observed (✓) | Not Observed (✗) | Frequency (✓) | Percentage (%) |
|---|---|---|---|---|
| **Learners are actively participating and engaged** | ✓ | ✗ | 6 | 67% |
| **Learners collaborate or interact while using AI tools** | ✓ | ✗ | 5 | 56% |
| **Learners of varying abilities are engaged** | ✓ | ✗ | 4 | 44% |

**Source: Primary Data**

Researcher observations confirm that AI tools enhance learner engagement in science classes. In 67% of observed lessons, pupils actively engaged during video simulations and interactive demonstrations by asking questions and showing curiosity behaviors aligned with Constructivist Theory. In 56% of classes, learners collaborated around AI content; however, limited access to devices restricted direct interaction. Teachers often used personal smartphones, resulting in only 44% of lessons showing inclusive engagement across all ability levels. This reflects the infrastructure gap noted by Namyalo & Okello (2023), where limited hardware and unequal access constrain AI's full impact. Overall, while AI fosters interest, collaboration, and feedback, its inclusive potential remains unrealized without better infrastructure and teacher training, particularly in rural settings.

### 4.3 Transforming Pedagogy: AI's Role in Shaping Teaching Practices

The integration of Artificial Intelligence (AI) in science classrooms is reshaping pedagogical approaches from traditional, teacher-centered instruction to more learner-centered, facilitative models. As shown in Table 5, the experiences of learners and educators in this study provide insight into this transformation.

**Table 5: Pupils' Responses on Pedagogical Shift**

| Theme | Response | Frequency | Percentage (%) |
|---|---|---|---|
| **Science teachers' frequency of using AI tools** | Sometimes | 17 | 56.7% |
| | Rarely | 8 | 26.7% |
| | Often | 5 | 16.6% |
| **Support given on use of AI tools** | Guidance and explanation | 20 | 66.7% |
| | Little or no help | 10 | 33.3% |

**Source: Primary Data**

More than half of the pupils (56.7%) reported that AI tools are used only occasionally, mainly during special events, indicating that AI integration remains superficial in daily classroom practice. Only 16.6% said their teachers used AI frequently, highlighting a gap between AI's potential and its consistent use in rural science teaching. This aligns with Okello and Mbabazi (2025a), who noted that inadequate teacher training limits sustained AI integration. Holmes et al. (2019) emphasized that AI can transform teachers into facilitators of learning, but only if they are empowered to manage this shift. While 66.7% of pupils appreciated teacher guidance during AI use supporting Wang et al. (2021) on the value of real-time support 33.3% received little or no help, often due to teachers' lack of confidence or skills, as also observed by Adeyemi et al. (2024).

### Teacher Perspectives on Pedagogical Transformation

Teacher perspectives show cautious optimism about AI use in classrooms: only 11.1% strongly agreed they frequently use AI tools, 55.6% agreed, and 33.3% were neutral, indicating that AI integration is emerging but not yet habitual, likely due to infrastructural challenges. All teachers acknowledged AI's role in personalizing instruction, with 44.4% strongly agreeing and 55.6% agreeing, supporting Johnson et al. (2023) and Tadesse & Muluneh (2024b) on AI's ability to provide targeted feedback and differentiated learning. Regarding confidence, 77.8% agreed they felt capable of using AI, while 22.2% were neutral, showing ongoing needs for capacity building as noted by Owusu et al. (2023). Peer collaboration was somewhat evident, with 55.6% agreeing they engage colleagues on AI use, though 44.4% were neutral, reflecting Okello and Mbabazi's (2025b) call for structured teacher development programs.

### Researcher's Observations on Pedagogical Shift

Field observations found that in 56% of classes, teachers shifted from lecture-based teaching to facilitative engagement, using AI tools like simulations and quizzes to promote inquiry, consistent with Holmes et al. (2019) and Constructivist Theory. However, 33% of lessons were disrupted by poor connectivity and limited device access, forcing teachers to revert to traditional methods, highlighting challenges identified by Ochieng et al. (2024). These findings suggest AI is beginning to influence science teaching toward personalized, learner-centered approaches, but progress is uneven due to limited training, intermittent use, and infrastructural issues. Literature from Rwanda and Kenya underscores that systemic support through policy, peer networks, and reliable technology access is essential for meaningful AI integration (Tadesse & Muluneh, 2024b; Owusu et al., 2023).

### 4.4 Barriers and Challenges to AI Integration in Resource-Limited Schools

AI adoption in rural, resource-constrained schools like those in Bududa District faces several significant challenges, as highlighted by both the study findings and existing literature. Key barriers include infrastructural limitations such as frequent power outages and poor internet connectivity, which disrupt classroom activities and increase learners' cognitive load by shifting focus away from scientific content an issue aligned with UNESCO's (2023b) findings and emphasized in MOES Uganda (2024) and African Union (2025a) education technology plans. From a Cognitive Load Theory perspective (Sweller, 1994), these disruptions raise extraneous cognitive load, reducing lesson effectiveness. Teachers' limited digital competence also emerged as a major obstacle, with many lacking the training and confidence needed to effectively use AI tools, consistent with Adeyemi et al. (2024) and Namyalo and Okello (2023). This undermines their role as constructivist facilitators (Vygotsky, 1978), leading to reduced learner engagement and a fallback on traditional methods. Access to devices was another constraint; with shared or limited equipment, learners were often passive observers rather than active participants, contradicting the principles of constructivist pedagogy (Holmes et al., 2019). Finally, gaps between national digital education strategies and school-level implementation were evident. Despite clear policy direction from the African Union (2025b) and MOES Uganda (2024), schools lacked sufficient training opportunities, institutional support, and localized AI content. In contrast to more successful examples in Ethiopia and Kenya (Adebe & Wondimu, 2025a; Mumo & Otieno, 2024a), Bududa's teachers expressed a strong desire for culturally relevant resources and more contextualized training.

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**Table 6: Researcher's Observations on Barriers to AI Integration**

| Theme | Observation Item | Observed (✓) | Not Observed (✗) | Frequency (✓) | Percentage (%) |
|---|---|---|---|---|---|
| **Infrastructure** | Consistent electricity and internet available | ✗ | ✓ | 3 | 33 |
| **Teacher Readiness** | Teachers confident in using AI tools | ✓ | ✗ | 5 | 56 |
| **Device Access** | Sufficient digital devices for hands-on learner engagement | ✗ | ✓ | 2 | 22 |
| **Policy & Support** | School-level policies or training programs for AI integration | ✗ | ✓ | 1 | 11 |

**Source: Primary Data**

The presentation and discussion emphasize that, from a constructivist perspective, effective learning requires active engagement, guided by skilled teachers and supported by appropriate resources (Vygotsky, 1978). In Bududa, this ideal is compromised by infrastructural deficiencies and limited teacher preparedness, which restrict AI's effectiveness in facilitating collaborative knowledge construction. Additionally, Cognitive Load Theory illustrates how technological unreliability and lack of clear teacher guidance increase extraneous cognitive load, making it harder for learners to process new scientific content (Sweller, 1994). These findings align with existing literature, confirming that unless infrastructure, teacher training, and policy issues are addressed, AI integration in resource-limited contexts will remain fragmented. The study therefore advocates for localized, low-cost AI solutions, improved professional development for teachers, and strengthened institutional support to realize AI's full potential in delivering meaningful, learner-centered science education.

### 4.5 Conclusion

In conclusion, the study highlights the transformative potential of AI tools in enhancing primary science education in rural settings, particularly in improving academic performance, learner engagement, and pedagogical practices. However, it also underscores the need to address key barriers such as limited infrastructure, inadequate teacher training, and misalignment with curricula. For AI integration to be effective and equitable, targeted investments, inclusive strategies, and context-specific implementation are essential. These findings provide a vital basis for the study's final chapter, which outlines the practical implications, recommendations, and overall conclusions.

### 4.6 Recommendations of the study

To effectively integrate AI in science classrooms, governments and development partners must invest in infrastructure such as electricity, internet, and digital devices, while also promoting offline AI tools for rural areas. Teachers need continuous professional development in AI pedagogy and peer mentorship to build digital competence. AI should support learner-centered approaches like inquiry-based and experiential learning, with tasks designed to manage cognitive load. Education policymakers must establish clear, context-specific guidelines for AI use in schools, and schools should implement internal plans including AI-use schedules and ICT support teams. AI tools must be culturally and linguistically relevant, with adaptive features to support learners of all abilities, ensuring inclusive and equitable learning experiences.

### 4.7 Implications for Science Teaching and Learning

The integration of AI in science education is transforming classrooms by shifting teachers' roles from information providers to facilitators and learning coaches, enabling more personalized and responsive instruction. AI tools enhance student engagement, motivation, and participation, especially through interactive methods like group work and visual simulations. They also support more inclusive education by addressing diverse learning needs, provided teachers are equipped to use them effectively. For rural and under-resourced areas, successful implementation depends on context-appropriate, affordable, and offline-capable solutions that align with local curricula. Strategic integration and proper sequencing of AI use are crucial to ensure that technology supports learning without overwhelming students.

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