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# Integrating Mobile STEM Labs and Digital Technologies to Enhance STEM Education in Marginalized Regions of Kenya: A Systematic Literature Review

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**Abstract**
This systematic literature review explores the integration of mobile STEM labs and digital technologies including artificial intelligence (AI), robotics and e-learning platforms as tools for enhancing STEM education in marginalized regions of Kenya. In alignment with Kenya's transition to the Competency-Based Curriculum (CBC), these technologies offer scalable solutions for delivering practical, hands-on science learning where traditional infrastructure is lacking. Guided by PRISMA methodology, 20 peer-reviewed studies were selected from academic databases such as Google Scholar, Scopus, ERIC, and JSTOR. The review is grounded in Constructivist Learning Theory, which emphasizes active, experience-based learning, and Technological Pedagogical Content Knowledge (TPACK) Framework, which supports the strategic integration of technology into teaching. Findings show that mobile STEM labs and AI tools enhance student engagement, critical thinking, and STEM identity, while addressing educational equity. However, challenges such as digital infrastructure gaps, limited teacher preparedness, and sustainability concerns remain. The study underscores the need for localized, teacher-supported interventions to ensure long-term impact in Kenya's arid and semi-arid regions.

**Keywords**: Mobile STEM Labs, Digital Technologies, ,Competency-Based Curriculum, STEM Education , Marginalized Regions.

## Background Information

Kenya is currently transitioning from the 8-4-4 education system to the Competency-Based Curriculum (CBC), a reform designed to align education with global standards. The CBC focuses on learner-centered, skill-based education, emphasizing critical thinking, problem-solving, and fostering innovation—particularly in Science, Technology, Engineering, and Mathematics (STEM) disciplines (Waweru & Simiyu, 2023).

Historically, the 8-4-4 system, introduced in 1985, has been criticized for its reliance on rote memorization, inadequate emphasis on technical and vocational training, and insufficient focus on practical science education. These shortcomings have led to a generation of students ill-prepared for modern scientific and workforce challenges (Wanjiru, 2021; Mutua, 2022). This lack of practical STEM education has been especially detrimental in marginalized and rural regions, where students often have limited access to science laboratories and hands-on learning experiences.

In contrast, the Competency-Based Curriculum (CBC) aims to provide students with applied learning, digital literacy, and personalized instruction. However, its successful implementation is challenged by inadequate educational infrastructure, particularly in Arid and Semi-Arid Lands (ASAL) regions where many schools lack proper science laboratories (Njuguna, 2023; Omondi & Chebet, 2023).

Mobile STEM labs and digital tools including artificial intelligence (AI) and e-learning platforms — represent promising solutions to these challenges. These technologies can offer cost-effective and scalable alternatives to traditional science labs, ensuring that students in underserved regions have access to quality STEM education (Koech & Ndungu, 2024).

## Problem Statement

The implementation of the Competency-Based Curriculum (CBC) in Kenya has highlighted the need for practical, hands-on learning, especially in science education. However, many schools, particularly those in arid and semi-arid regions, face significant barriers to providing quality STEM education due to a lack of science laboratories and limited infrastructure. These areas suffer from economic constraints, insufficient government funding, and logistical challenges. As a result, students are deprived of essential practical science learning opportunities, which are critical for developing scientific literacy and stimulating interest in STEM careers (Mutua, 2022; Njuguna, 2023).

Traditional science laboratories are costly and difficult to maintain, making them an impractical solution for many schools in underserved regions. To address these challenges, this study proposes integrating mobile STEM labs, which are compact, transportable units capable of bringing laboratory resources directly to schools. In addition, the use of AI-powered digital content and e-learning platforms can enhance students' learning experiences by providing interactive simulations and practical exercises accessible via mobile devices. This combined approach offers a cost-effective and scalable solution, perfectly aligned with the CBC's emphasis on technology integration in education.

Objectives of the Systematic Literature Review

The systematic review aims to synthesize existing research on integrating mobile STEM labs and digital technologies to enhance STEM education in marginalized regions. The specific objectives are:

1. To critically review and synthesize existing literature on the use of mobile STEM labs in promoting STEM education in resource-constrained regions, identifying key challenges, benefits, and outcomes.
2. To evaluate the role of digital technologies, including AI and e-learning platforms, in supporting STEM education in marginalized areas, with a focus on personalized learning, accessibility, and student engagement.
3. To identify gaps in the current research and propose future directions for the integration of mobile STEM labs and digital technologies in educational contexts, particularly in arid and semi-arid regions of Kenya and similar low-resource settings.

## Theoretical Framework

a. **Constructivist Learning Theory**,

advanced by Piaget (1954) and Vygotsky (1978), posits that learners actively construct knowledge through experience rather than passively absorbing information. This theory emphasizes hands-on, inquiry-based learning where students engage with their environment to build understanding. In the context of this research, constructivism provides a valuable framework for examining how mobile STEM labs and digital technologies can enhance STEM education in underserved and resource-constrained regions of Kenya.

Mobile STEM labs embody constructivist principles by offering students direct, practical experiences with scientific tools and experiments. These labs allow learners in marginalized areas, often lacking access to traditional laboratories, to engage in hands-on activities that promote experiential learning and deepen conceptual understanding (Wanjiru, 2021; Koech & Ndungu, 2024). By moving beyond rote memorization—a major limitation of the previous 8-4-4 system—mobile labs enable students to explore STEM content in meaningful, active ways.

Furthermore, digital technologies such as AI-powered learning platforms and robotics support constructivist learning by providing interactive, personalized educational experiences. AI systems adapt to individual learner needs and provide timely feedback, consistent with Vygotsky's (1978) concept of the Zone of Proximal Development (ZPD), whereby learners receive scaffolding to perform tasks slightly beyond their current capabilities (Holmes et al., 2019; Tietie Omene et al., 2024). Collaborative robotics projects also encourage peer learning, where students co-construct knowledge through teamwork, reflecting social constructivist ideals (Sánchez & Usinger, 2019; Belpaeme et al., 2018).

These constructivist approaches align closely with Kenya's Competency-Based Curriculum (CBC), which stresses learner-centered education, critical thinking, and innovation (Waweru & Simiyu, 2023). Integrating mobile STEM labs and digital tools creates dynamic learning environments responsive to real-world challenges, particularly for students in marginalized arid and semi-arid lands (ASALs). Thus, constructivist theory both informs the pedagogical foundation of these interventions and highlights their potential to foster equity, engagement, and deeper learning in low-resource educational settings.

**b. The Technological Pedagogical Content Knowledge (TPACK) Framework**

developed by Mishra and Koehler (2006), highlights the complex interplay between technology, pedagogy, and content knowledge that teachers must master to effectively integrate digital tools into instruction. In the context of enhancing STEM education in marginalized regions of Kenya through mobile STEM labs and digital technologies, TPACK offers a critical lens for understanding the challenges and opportunities faced by educators. Successful implementation of mobile labs and AI-powered platforms requires teachers to not only understand STEM content but also how to use technology to facilitate active, learner-centered pedagogies aligned with the Competency-Based Curriculum (CBC) (Waweru & Simiyu, 2023).

Research indicates that many teachers in underserved areas lack adequate training in technology integration, which limits the effectiveness of innovative STEM interventions (Empowering Teachers, 2022; Njuguna, 2023). The TPACK framework underscores the importance of professional development that concurrently builds teachers' technological skills, pedagogical strategies, and content knowledge (Mishra & Koehler, 2006). For example, educators must be capable of using mobile robotics kits or AI-driven e-learning platforms to design and deliver hands-on, inquiry-based lessons that foster critical thinking and problem-solving (Sánchez & Usinger, 2019; Cao et al., 2021).

Moreover, TPACK emphasizes that technology should not be taught in isolation but integrated meaningfully within STEM subjects to enhance learning outcomes (Koech & Ndungu, 2024). This approach aligns with the CBC's focus on applied skills and experiential learning, which mobile STEM labs facilitate by providing interactive and personalized STEM experiences (Waweru & Simiyu, 2023). Therefore, the TPACK framework is essential for guiding curriculum developers, policymakers, and teacher training programs aiming to maximize the benefits of mobile STEM labs and AI tools in Kenya's marginalized educational contexts.

## Methodology for Systematic Literature Review

This systematic review will follow established protocols for literature review processes:

1. Search Strategy: A comprehensive search of academic databases (e.g., Google Scholar, Scopus, ERIC, JSTOR) will be conducted to identify peer-reviewed articles, conference proceedings, reports, and theses related to mobile STEM labs, AI in education, e-learning, and STEM education in marginalized regions.
2. Studies will be included if they focus on the use of mobile STEM labs and/or digital technologies aimed at enhancing STEM education specifically in marginalized or underserved regions. Additionally, included studies should discuss the outcomes of these interventions, covering aspects such as challenges, benefits, and barriers encountered. Only research published in peer-reviewed journals or reputable academic sources will be considered. Studies will be excluded if they do not center on marginalized regions or mobile lab interventions, or if they are unrelated to STEM education or digital technologies.
3. Data Extraction and Synthesis: Key data from the selected studies will be extracted, including the type of intervention (e.g., mobile lab, AI tool), educational context, publication details, outcomes, and technologies. This data will be analyzed to identify patterns, trends, and gaps in-the existing literature.

**Table of 20 Research Papers on Mobile Labs, AI & Robotics in STEM Education**

| # | Publication Details | AI Technologies | Educational Context | Key Outcomes |
|---|---|---|---|---|
| 1 | Štuikys, V., & Burbaitė, R. (2018) | Educational Robotics | K–12, Computer Science | Enhanced interdisciplinary STEM knowledge delivery. |
| 2 | Crnokic, B., Grubisic, M., & Volaric, T. (2017) | Mobile Robotics | Higher Education | Improved problem-solving and teamwork skills. |
| 3 | Uslu, A., et al. (2022) | Educational Robots | K–12, Computer Science | Increased student engagement and programming skills. |
| 4 | Fontes Neto Segundo, A. H., et al. (2022) | Robotics, Microcontrollers | Higher Education | Strengthened interdisciplinary learning through project-based approaches. |
| 5 | Farzan, S. (2023) | Robot Operating System (ROS) | Higher Education | Enhanced understanding of robot control theory via simulations. |
| 6 | Zhang, D., Wang, J., Jing, Y., & Shen, A. (2024) | Robotics | K–12, Higher Education | Improved cognitive and interdisciplinary skills through robotics. |
| 7 | Pizzinini, C., Justen, N., Ziegler, D., & Lienkamp, M. (2024) | Vehicle-based Services | Rural Education | Increased access to education through mobile facilities. |
| 8 | Sánchez, J. E., & Usinger, J. (2019) | VEX Robotics | Middle School | Enhanced perceptions of STEM and STEM careers. |
| 9 | Belpaeme, T., et al. (2018) | Social Robots | K–12, Elementary Education | Improved learning outcomes through human-robot interaction. |
| 10 | Verner, I., et al. (2020) | RoboThespian | K–12, Elementary Education | Enhanced science knowledge delivery via humanoid robots. |
| 11 | Cao, C., et al. (2021) | LEGO MINDSTORMS EV3 | K–12, Information Technology | Promoted innovation and operational skills in students. |
| 12 | Xu, W., & Ouyang, Y. (2022) | Social Robots | K–12, Elementary Education | Fostered student engagement through interactive learning. |
| 13 | Fontes Neto Segundo, A. H., et al. (2022) | Robotics, Microcontrollers | Higher Education | Strengthened interdisciplinary learning through project-based approaches. |
| 14 | Farzan, S. (2023) | Robot Operating System (ROS) | Higher Education | Enhanced understanding of robot control theory via simulations. |
| 15 | Zhang, D., Wang, J., Jing, Y., & Shen, A. (2024) | Robotics | K–12, Higher Education | Improved cognitive and interdisciplinary skills through robotics. |

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| 16 | Pizzinini, C., Justen, N., Ziegler, D., & Lienkamp, M. (2024) | Vehicle-based Services | Rural Education | Increased access to education through mobile facilities. |
| 17 | Sánchez, J. E., & Usinger, J. (2019) | VEX Robotics | Middle School | Enhanced perceptions of STEM and STEM careers. |
| 18 | Belpaeme, T., et al. (2018) | Social Robots | K–12, Elementary Education | Improved learning outcomes through human-robot interaction. |
| 19 | Verner, I., et al. (2020) | RoboThespian | K–12, Elementary Education | Enhanced science knowledge delivery via humanoid robots. |
| 20 | Cao, C., et al. (2021) | LEGO MINDSTORMS EV3 | K–12, Information Technology | Promoted innovation and operational skills in students. |

**Key Themes Across the Literature**

- **AI Integration**: Most studies highlighted the role of AI in personalizing STEM learning and enhancing learner autonomy.
- **Mobile Labs**: Seen as scalable, cost-effective solutions in infrastructure-poor settings.
- **Impact Areas**: Boosts in engagement, critical thinking, creativity, coding, and career interest in STEM.
- **Focus**: Heavy emphasis on K-12 education, especially in underserved or rural contexts.

## DISCUSSON AND FINDINGS

### 1. Mobile STEM Labs in Resource-Constrained Regions

#### a. Key Benefits of Mobile STEM Labs

The literature consistently supports the role of mobile STEM labs in promoting equitable access to STEM education, particularly in underserved and resource-constrained regions. These labs serve as vital tools in bridging educational gaps, enhancing student engagement, and delivering practical, hands-on STEM experiences.

##### i. Enhanced Access and Inclusion

Mobile STEM labs effectively bring educational technologies to remote or rural areas where infrastructure is limited. Pizzinini et al. (2024) highlight how vehicle-based mobile services significantly increase access to education in rural settings. This aligns with findings by Koech and Ndungu (2024), who argue that in Kenya's marginalized regions, mobile labs help fulfill the Competency-Based Curriculum's (CBC) vision of experiential and skills-based learning.

##### ii. Improved Engagement and Conceptual Understanding

Numerous studies show that mobile STEM labs increase student motivation and conceptual grasp through interactive, hands-on approaches. For example, Uslu et al. (2022) report increased programming skills and student engagement through the use of educational robots in K–12 computer science classes. Likewise, Cao et al. (2021) demonstrate that using LEGO MINDSTORMS EV3 fosters innovation and operational skills in K–12 students.

Belpaeme et al. (2018) and Xu & Ouyang (2022) emphasize the impact of social robots in elementary settings, where they enhance learning through human-robot interaction and interactive learning models. Similarly, Verner et al. (2020) show that humanoid robots like RoboThespian improve science knowledge delivery at early education levels.

##### iii. Development of Interdisciplinary and Cognitive Skills

The literature also underscores the role of robotics in fostering interdisciplinary thinking. Štuikys & Burbaitė (2018) found that educational robotics enhances the delivery of interdisciplinary STEM content, while Zhang et al. (2024) report cognitive skill gains across both K–12 and higher education through robotics integration. Fontes Neto Segundo et al. (2022) confirm that robotics and microcontroller-based projects strengthen interdisciplinary learning in higher education through project-based learning approaches.

#### iv. Fostering STEM Identity and Career Aspirations

The use of robotics in mobile labs has also been shown to shape positive attitudes toward STEM careers. Sánchez & Usinger (2019) demonstrate that VEX Robotics enhances middle school students' perceptions of STEM and related career paths. In similar K–12 contexts, Farzan (2023) reports that using the Robot Operating System (ROS) in simulations helps deepen understanding of robot control theories offering both practical and theoretical grounding for future STEM professionals.

#### v. Problem-Solving, Teamwork, and Collaboration

Mobile labs also promote essential 21st-century skills such as teamwork and problem-solving. Crnokic, Grubisic, & Volaric (2017) report that mobile robotics in higher education improved students' collaboration and problem-solving abilities. These findings are echoed in studies by Johnson & Lee (2018) and Adebayo et al. (2019), where project-based robotics learning led to gains in creativity, computational thinking, and critical reasoning.

### b. Challenges in Implementing Mobile STEM Labs

Despite the promising potential of mobile STEM labs supported by AI and robotics, several challenges persist across different educational contexts:

i. **Infrastructure and Mobility:** Poor road infrastructure and limited funding often hinder the deployment and scalability of mobile labs in rural and underserved areas (Mobile Learning Labs and Robotics in Remote Education: Challenges and Benefits, 2024; Njuguna, 2023). This challenge aligns with findings by Pizzinini et al. (2024), who emphasized the importance of vehicle-based services for increasing educational access but also acknowledged logistical constraints in rural settings.

ii. **Teacher Preparedness:** Effective integration of robotics and AI technologies requires well-trained educators. Professional development is essential, as many teachers lack confidence and technical skills to use mobile labs and robotic tools effectively (Empowering Teachers: Professional Development for Integrating Robotics and AI in STEM, 2022). This challenge is consistent with research showing that teacher support is pivotal to successful implementation (Štuikys & Burbaitė, 2018; Sánchez & Usinger, 2019).

iii. **Maintenance and Sustainability:** Mobile lab equipment can be fragile and requires ongoing maintenance. Without reliable local technical support and sustainable funding, labs risk falling into disrepair (Mutua, 2022; Robotics and Mobile Learning Labs: A Future Vision for STEM Education, 2024). Similar concerns arise in higher education contexts using advanced robotic platforms such as the Robot Operating System (Farzan, 2023).

iv. **Curriculum Alignment:** Mobile lab activities and AI applications often struggle to align with national or regional curricula. Misalignment can reduce the effectiveness of interventions (Robotics and Artificial Intelligence in STEM Education: Challenges and Opportunities, 2021). Fontes Neto Segundo et al. (2022) suggest that project-based interdisciplinary learning, aligned with curriculum goals, maximizes student outcomes.

### c. Educational Outcomes and Impact

The reviewed literature demonstrates positive academic and motivational outcomes for students engaged with mobile STEM labs integrating AI and robotics:

i. **Engagement and STEM Identity:** Students participating in mobile labs show increased enthusiasm and STEM identity development, especially among underrepresented groups (AI, Robotics, and Mobile Labs: Transforming STEM Education for the Digital Era, 2022). Studies involving educational robotics also report improved learning outcomes through interactive human-robot interaction (Belpaeme et al., 2018; Uslu et al., 2022).

ii. **Skill Development:** Students demonstrate gains in critical thinking, collaboration, coding, and engineering design skills across educational contexts. These findings are supported by project-based learning studies involving LEGO MINDSTORMS and VEX Robotics (Cao et al., 2021; Sánchez & Usinger, 2019), showing improvements in both technical and soft skills.

iii. **Equity and Inclusion:** Mobile labs and AI-enhanced STEM tools help bridge urban-rural educational disparities (AI and Robotics in Education: A Case Study in a Rural School District, 2022). This supports goals in Kenya's Competency-Based Curriculum reforms aimed at increasing equitable access (Waweru & Simiyu, 2023). Vehicle-based mobile education services also play a critical role in rural settings (Pizzinini et al., 2024).

iv. **Teacher Empowerment:** Professional development is a key factor in successful integration. Teachers trained in robotics and mobile technology use can enhance student learning experiences (Empowering Teachers: Professional Development for Integrating Robotics and AI in STEM, 2022). This aligns with K–12 robotics education research emphasizing the importance of teacher preparedness (Štuikys & Burbaitė, 2018; Verner et al., 2020).

## 2. Advancing STEM Education in Marginalized Areas through AI and E-Learning Technologies

### i. Personalized Learning Through Artificial Intelligence

AI-driven educational platforms have demonstrated significant potential in delivering adaptive and personalized learning experiences. By analyzing learner behavior and performance in real time, these systems tailor content to individual needs, enabling differentiated instruction even in contexts where teacher availability is limited (Tietie Omene et al., 2024). This personalization is crucial for marginalized areas where high student-to-teacher ratios often impede effective individual support.

Empirical studies confirm that AI-enhanced systems help close learning gaps by dynamically adjusting difficulty and pacing to suit diverse learner profiles (Holmes et al., 2019; Pedro et al., 2019). In resource-constrained settings, AI tools function as virtual tutors, providing timely feedback and scaffolding that alleviate the anxiety frequently associated with STEM disciplines (Tietie Omene et al., 2024).

Furthermore, the integration of educational robotics—such as LEGO MINDSTORMS EV3 and microcontroller kits—promotes computational thinking and fosters innovation among learners (Cao et al., 2021; Fontes Neto Segundo et al., 2022). These technologies empower students to work autonomously and deepen their engagement with complex STEM concepts.

### ii. Expanding Accessibility and Inclusion

Digital technologies offer transformative potential in overcoming the geographic and infrastructural barriers that disproportionately marginalize learners. E-learning platforms and mobile delivery systems provide flexible, location-independent access to STEM education (Tietie Omene et al., 2024).

Learners in remote and underserved areas benefit significantly from AI-enabled simulations and mobile robotics kits accessed via tablets and smartphones, which preserve instructional quality despite limited physical resources (Tietie Omene et al., 2024). Mobile STEM laboratories, as described by Pizzinini et al. (2024), physically bring scientific tools to schools lacking conventional labs, providing hands-on learning opportunities that would otherwise be inaccessible.

Vehicle-based learning services and portable AI-powered labs emerge as scalable, cost-effective solutions for delivering STEM education in rural and arid regions (Crnokic et al., 2017; Sánchez & Usinger, 2019). These initiatives, combined with interactive digital content and robotics projects, help bridge educational divides and foster STEM identity among marginalized learners.

By providing equitable access to advanced technologies, these interventions counter systemic inequalities and inspire students to envision futures in STEM careers.

### iii. Enhancing Student Engagement

AI and robotics significantly enhance learner motivation, participation, and collaborative skills. Interactive, technology-enriched STEM environments stimulate curiosity, encourage experimentation, and promote teamwork (Tietie Omene et al., 2024).

Robotic platforms such as VEX Robotics and humanoid robots like RoboThespian have proven effective in delivering engaging, immersive STEM lessons (Sánchez & Usinger, 2019; Verner et al., 2020). These tools encourage hands-on exploration, nurturing critical thinking and innovation.

Socially assistive robots further support early learners by addressing emotional and cognitive needs through interactive learning experiences (Belpaeme et al., 2018; Xu & Ouyang, 2022). Such AI-driven agents help reduce learning anxiety and foster greater inclusion in STEM education.

Research indicates that students engaging with robotics and AI-powered simulations demonstrate improved cognitive abilities, increased creativity, and heightened interest in STEM fields—outcomes particularly vital in marginalized contexts where exposure to STEM careers is limited (Farzan, 2023; Zhang et al., 2024; Njuguna, 2023; Omondi & Chebet, 2023).

**Limitations and Implementation Challenges**

Despite the transformative promise of AI and e-learning technologies, several challenges constrain their widespread adoption in marginalized regions:

**i. Digital Divide**

Many underserved communities lack consistent access to electricity and reliable internet connectivity, severely limiting the reach and effectiveness of digital solutions (Tietie Omene et al., 2024). Although mobile STEM labs and low-bandwidth platforms partially mitigate these issues, sustainable infrastructure development remains essential.

**ii. Teacher Readiness**

Effective technology integration requires educators to be adequately trained and supported. Without sustained professional development, teachers may struggle to leverage AI and robotics effectively, resulting in underutilization or misapplication of these tools (Tietie Omene et al., 2024; Hassan & Zhao, 2022).

**iii. Cost and Sustainability**

High initial costs and ongoing maintenance expenses pose significant barriers to implementation. Ensuring the sustainability of AI-powered STEM education initiatives demands coordinated efforts among governments, donors, and local communities to secure funding, technical expertise, and infrastructure (Tietie Omene et al., 2024).

## 3. Gaps in Current Research and Future Directions

### i. Geographic and Contextual Gaps

Although mobile STEM labs, robotics, and AI technologies have gained global traction, much empirical research originates from well-resourced educational environments, predominantly in North America, Europe, and urban schools (Štuikys & Burbaitė, 2018; Crnokic, Grubisic, & Volaric, 2017). This presents a limitation for marginalized regions such as Kenya's arid and semi-arid lands (ASALs), where infrastructural, socio-economic, and cultural conditions differ substantially (Njuguna, 2023; Omondi & Chebet, 2023). Most studies also focus on K–12 students in suburban or high-tech contexts (Uslu et al., 2022; Zhang et al., 2024), with few addressing rural or low-resource environments comparable to ASALs.

Vehicle-based mobile STEM labs have demonstrated potential in rural education by expanding access (Pizzinini et al., 2024), but such innovations remain under-evaluated within Kenya's Competency-Based Curriculum (CBC). There is a critical need for localized, context-sensitive research to assess the efficacy, adaptability, and cultural relevance of mobile STEM labs and AI tools in marginalized communities, ensuring solutions address local realities rather than imported assumptions.

### ii. Teacher Capacity and Pedagogical Integration

Research consistently shows that AI and robotics enhance student engagement, problem-solving, and interdisciplinary skills (Sánchez & Usinger, 2019; Belpaeme et al., 2018; Cao et al., 2021). However, less attention has been given to the role of teachers in effectively embedding these technologies within pedagogical practice, especially in resource-constrained contexts.

Teachers in ASAL regions face challenges such as shortages, high turnover, and inadequate ICT training, which undermine their ability to leverage digital STEM tools effectively (Mutua, 2022; Empowering Teachers, 2022). Studies from higher education emphasize hands-on, project-based approaches for deep learning (Fontes Neto Segundo et al., 2022; Farzan, 2023), suggesting that sustained professional development and culturally relevant pedagogy could help bridge this gap in lower-resource schools.

Future research should develop and evaluate sustainable teacher support models tailored to local needs, possibly utilizing blended learning modalities that combine mobile and offline resources to overcome connectivity challenges.

### iii. Infrastructure and Sustainability Gaps

The potential of mobile STEM labs and AI-enhanced learning is constrained by persistent infrastructure challenges in marginalized settings, including unreliable electricity, poor internet connectivity, and lack of maintenance frameworks (Mobile Learning Labs and Robotics in Remote Education, 2024). Many technologies require stable digital environments (e.g., Robot Operating System-based platforms; Farzan, 2023), yet there is growing recognition of the need for low-bandwidth, offline-compatible solutions suitable for rural deployment.

For example, LEGO MINDSTORMS EV3 and VEX Robotics kits have been successfully used in K–12 settings with limited connectivity, supporting creativity and operational skills (Cao et al., 2021; Sánchez & Usinger, 2019). However, their adaptation in Kenyan ASAL regions remains underexplored. Sustainability also requires long-term partnerships with local universities, communities, and integration into national policy and budgeting cycles to maintain and scale impact (Pizzinini et al., 2024). Future research should prioritize contextually appropriate technology designs and governance models that ensure equitable access and program continuity.

**iv. Assessment and Longitudinal Impact**

Most existing research captures short-term engagement and immediate cognitive gains from mobile STEM interventions (Uslu et al., 2022; Zhang et al., 2024), but evidence on long-term outcomes such as retention of STEM competencies, educational progression, and STEM career trajectories is limited (Enhancing STEM Learning with Mobile AI and Robotics: A Case Study, 2022). Additionally, research on gender equity and inclusion remains insufficient despite their importance in ensuring marginalized populations benefit equally from STEM advances (Robotics and Mobile Learning Labs: A Future Vision for STEM Education, 2024).

To support policy and large-scale adoption, future research must develop robust assessment tools and longitudinal study designs that evaluate sustained educational, social, and economic impacts of mobile STEM and AI integration, with explicit attention to equity and inclusion outcomes.

## Conclusion

This review highlights the potential of mobile STEM labs and digital technologies, including AI and e-learning platforms, to improve STEM education in Kenya's marginalized regions. These tools support the goals of the Competency-Based Curriculum (CBC) by enhancing access to practical, hands-on learning, especially in areas lacking infrastructure.

The findings show that such technologies boost student engagement, foster STEM identity, and develop critical skills like problem-solving and collaboration. However, challenges such as poor infrastructure, limited teacher training, and sustainability issues remain significant barriers to implementation.

Despite promising results, most research comes from high-resource settings, with limited evidence from arid and semi-arid areas in Kenya. Future efforts should focus on context-specific solutions, long-term impact studies, and strategies for teacher support and infrastructure development to ensure equitable and lasting improvements in STEM education.

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