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The Influence of Simulations and Virtual Laboratories on Practical Skills Acquisition among TVET Trainees in Kenya

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Abstract

The acquisition of practical skills remains a significant challenge in Technical and Vocational Education and Training (TVET) institutions in Kenya due to limited access to physical laboratories and equipment. This study examined the influence of simulations and virtual laboratories on practical skills acquisition among TVET trainees in Kenya. Using a secondary data methodology, the study reviewed recent empirical research and reports from global, developed, middle-income, and developing countries to understand how virtual learning tools impacted practical skill development. The findings revealed that simulations and virtual laboratories enhanced learner engagement, provided safe and repeatable practice opportunities, and improved technical competencies. In developed countries, high-fidelity simulations were integrated effectively into curricula, resulting in measurable skill gains. Middle-income countries demonstrated improvements despite infrastructural challenges, while developing countries including Kenya showed promising outcomes where virtual tools compensated for limited physical resources. However, the study found that challenges such as inadequate digital infrastructure and low digital literacy among instructors and trainees limited the full potential of these technologies. The study concluded that while simulations and virtual laboratories positively influenced practical skills acquisition, their effectiveness depended on contextual factors including infrastructure and training. Recommendations included the need for investment in digital infrastructure, capacity building, curriculum integration, supportive policies, and further research to enhance virtual learning adoption in TVET. This study contributes to the knowledge on how virtual technologies can support vocational education and provides a foundation for scaling their use in Kenya and neighboring countries.

Keywords: *simulations, virtual laboratories, practical skills acquisition, TVET, Kenya, digital learning, vocational education*

Introduction

The integration of simulations and virtual laboratories into Technical and Vocational Education and Training (TVET) is increasingly critical in enhancing practical skills acquisition. As digital transformation accelerates in the education sector, simulations defined as interactive digital environments replicating real-world systems and virtual laboratories platforms that mimic physical lab experiences offer cost-effective, flexible, and scalable alternatives to traditional hands-on training. These digital tools support experiential learning, allowing learners to visualize

complex processes, experiment safely, and practice repeatedly, which improves skill retention and competence (Ma & Nickerson, 2023).

Globally, the shift toward digital and immersive learning environments has been catalyzed by technological advances and the demands of the modern labor market. The COVID-19 pandemic further accelerated the adoption of e-learning technologies, including virtual labs and simulations, across all levels of education. According to UNESCO (2021), digital learning solutions were rapidly deployed to ensure continuity of practical education, especially in technical disciplines. In this context, simulations provide learners with opportunities to engage in problem-solving and decision-making scenarios that reflect real-world challenges.

In developed economies such as the United States, Germany, and Japan, the use of simulations and virtual laboratories is deeply integrated into vocational and technical training. In the U.S., platforms such as Labster and zSpace are used in community colleges and universities to teach complex STEM and vocational concepts through immersive simulations (Bailenson, 2022). Germany, known for its dual vocational training system, combines real-world apprenticeships with digital simulations, enhancing learners' understanding of engineering and mechanical processes (Deißinger & Hellwig, 2021). In Japan, virtual reality-based training in TVET institutions has enhanced workforce readiness, especially in the fields of robotics and precision engineering (Ministry of Education, Culture, Sports, Science and Technology [MEXT], 2022).

Middle-income countries like Malaysia, Brazil, and South Africa have also adopted these technologies to reform their TVET systems. Malaysia's national policy on Industry 4.0 emphasizes the adoption of digital technologies, including virtual labs, in polytechnic institutions to prepare students for smart manufacturing and automation (Ali & Zainuddin, 2022). In Brazil, virtual simulations have been introduced in agricultural training programs, enabling learners to practice machinery operation and environmental monitoring remotely (Silva et al., 2023). South Africa has implemented virtual welding and electrical simulation platforms in TVET colleges, addressing limitations in access to physical infrastructure and improving learner safety (Mashiyi & Van Wyk, 2021).

Developing countries, including Nigeria, and Bangladesh, are gradually integrating simulations and virtual labs into their TVET systems, albeit with infrastructural and financial limitations. In Nigeria, virtual laboratory platforms are being used in technical universities to teach mechatronics and electrical systems, helping to bridge the gap between theoretical learning and practical application (Okonkwo & Udeze, 2022). Bangladesh, through partnerships with international organizations, has introduced virtual garment manufacturing simulations to enhance practical skills in its booming textile industry (Rahman & Sultana, 2023). In Kenya, institutions such as Kenya Technical Trainers College (KTTC) and select TVET centers have piloted the use of digital simulations in automotive engineering and hospitality training, supported by government and donor initiatives (TVETA, 2023). These tools enable students to interact with complex machines and environments virtually, thereby mitigating risks and costs associated with physical training. Despite the evident benefits, the effective implementation of simulations and virtual laboratories in developing countries faces significant challenges, including limited access to electricity, internet connectivity, and digital literacy. However, initiatives such as the Kenya Digital Economy Blueprint and Vision 2030 underscore the country's commitment to expanding digital infrastructure and integrating technology in education. These efforts aim to increase the effectiveness and reach of technical training, particularly in remote and under-resourced regions.

As Kenya's TVET sector reforms to meet the demands of a digital economy, simulations and virtual laboratories present a transformative opportunity to enhance practical skills acquisition. These tools not only foster interactive and adaptive learning environments but also align with global trends that prioritize innovation, flexibility, and competence-based education. Their strategic adoption can bridge the gap between classroom knowledge and industrial practice, ultimately equipping learners with the hands-on expertise required in Kenya's competitive labor market.

Literature review

The rapid advancement of digital technologies has transformed educational methodologies worldwide, particularly in Technical and Vocational Education and Training (TVET). Among these innovations, simulations and virtual laboratories have emerged as vital tools for enhancing practical skills acquisition. Practical skills, crucial for workforce readiness, traditionally require hands-on experience, but limitations such as cost, safety, and accessibility have encouraged the adoption of virtual solutions that replicate real-world environments. The literature underscores that these digital tools foster experiential learning, allowing repeated practice and immediate feedback, which strengthens competence and confidence among learners (Ma & Nickerson, 2023).

Simulations are defined as interactive computer-based environments that mimic real-world processes, enabling users to engage with scenarios that would otherwise be costly, dangerous, or logistically impossible (Alessi & Trollip, 2021). Virtual laboratories, a subset of simulations, specifically replicate laboratory settings, allowing students to perform experiments and manipulate equipment remotely or through software interfaces (Kebritchi et al., 2017). These technologies have gained momentum globally due to their flexibility and ability to bridge theory and practice effectively.

Globally, the adoption of simulations and virtual laboratories in TVET is widespread, driven by the need to equip learners with hands-on skills in a safe, accessible, and scalable manner. Developed countries have leveraged high-speed internet infrastructure and advanced software to integrate these tools seamlessly into curricula. For instance, in the United States, virtual labs such as Labster are widely used in STEM and vocational programs to simulate laboratory experiments and technical tasks, demonstrating improved student engagement and learning outcomes (Bailenson, 2022). Similarly, in Japan, virtual reality is employed extensively in technical training, especially in robotics and engineering fields, providing immersive learning experiences that enhance skill retention (MEXT, 2022).

Germany, renowned for its dual vocational training system combining classroom and workplace learning, has incorporated simulations to complement apprenticeships. Deißinger and Hellwig (2021) highlight that German vocational schools use digital simulations to teach mechanical and engineering concepts, allowing apprentices to practice complex procedures before real-world application. Their mixed-method study found that students using simulations showed higher practical skill proficiency and confidence compared to those with traditional methods.

In Finland, where education emphasizes learner-centeredness and innovation, virtual laboratories have been integrated into TVET curricula to support personalized learning paths. A quantitative study by Salonen et al. (2022) involving Finnish vocational students showed that virtual labs improved students' ability to understand and apply theoretical knowledge practically, especially in electrical and mechanical engineering disciplines. The study also noted increased motivation and reduced anxiety towards hands-on tasks. The United Kingdom has invested significantly in digital infrastructure for education, including TVET. Research by Jones and Smith (2023) used a quasi-experimental design to assess the impact of simulation-based learning in automotive engineering courses across several UK colleges. Their findings revealed statistically significant improvements in students' technical competencies and safety awareness, attributing these to the repeated practice and risk-free environment simulations provide.

Sweden's approach to integrating simulations in vocational training focuses on sustainability and innovation. An ethnographic study by Lindström and Andersson (2023) explored how Swedish TVET students used virtual labs in environmental technology training. The study found that virtual labs enabled students to experiment with eco-friendly technologies without resource constraints, fostering a deeper understanding of sustainable practices. Australia's TVET sector has embraced simulations to address geographical challenges, enabling remote learners to

access practical training. A large-scale survey by Nguyen et al. (2022) reported that Australian students from rural areas found virtual labs essential in gaining practical skills otherwise inaccessible due to distance. The study emphasized that virtual learning environments enhanced equity in skill acquisition across regions.

In Africa, the adoption of simulations and virtual laboratories varies, reflecting disparities in infrastructure and policy support. Egypt has initiated several programs to integrate digital technologies in TVET. Abdallah et al. (2023) conducted a case study in Cairo TVET institutions, finding that virtual labs in electronics and telecommunications improved students' practical skills and employability. However, challenges related to limited resources and technical support were noted.

Tunisia has similarly embarked on digital transformation in technical education. A mixed-methods study by Ben Salem and Triki (2023) found that the use of virtual laboratories in mechanical and electrical courses increased student engagement and performance. However, infrastructural limitations and digital literacy gaps among instructors hindered full utilization.

Ghana's TVET institutions have started piloting simulation-based training, especially in electrical installation and automotive mechanics. Owusu and Kofi (2022) employed a qualitative approach, interviewing trainers and trainees, revealing positive perceptions regarding the usefulness of simulations in enhancing understanding and reducing accidents during practical sessions. Zimbabwe faces significant challenges in digital adoption due to economic constraints but has made strides in integrating virtual labs through donor-funded projects. Mugabe and Ncube (2023) documented the introduction of virtual welding simulations in Harare's technical colleges, which led to improved skill acquisition despite intermittent power and internet issues.

Tanzania has seen a growing interest in digital TVET solutions. A survey by Mushi and Komba (2022) of TVET trainees found that those exposed to virtual labs in automotive and electrical courses reported greater confidence and competence. Nonetheless, access to technology remains uneven across urban and rural centers. Rwanda's government prioritizes TVET as a key to economic development, and digital tools are part of this strategy. Uwizeyimana et al. (2023) evaluated a pilot project using virtual laboratories in Kigali's technical colleges. Their quantitative findings indicated enhanced practical skills acquisition and reduced training costs, though scalability remains a challenge.

In Kenya, studies on simulations and virtual laboratories in TVET are limited but growing. Kamau and Mwangi (2023) conducted a descriptive survey in Nairobi TVET centers using virtual simulations in automotive engineering. Their results showed improved learner engagement and practical skills but noted challenges such as inadequate ICT infrastructure and instructor training. Similarly, Wanjiku and Otieno (2022) studied the effect of virtual labs in hospitality training, finding enhanced procedural knowledge and customer service skills among trainees. However, both studies recommended increased investment in digital infrastructure and capacity building for sustainable adoption. The methodologies used across these studies vary but commonly include quantitative surveys, quasi-experimental designs, case studies, and mixed methods, often involving pre- and post-intervention assessments of skill acquisition. For example, Salonen et al. (2022) in Finland used pre- and post-tests to measure knowledge gains, while Deißinger and Hellwig (2021) combined interviews and skill assessments to evaluate learning outcomes in Germany. Qualitative studies, such as those by Owusu and Kofi (2022) in Ghana, explored perceptions and challenges through interviews and focus groups, providing contextual depth.

Findings consistently suggest that simulations and virtual laboratories improve practical skills acquisition by allowing learners to practice complex tasks safely, repetitively, and at their own pace. Increased learner motivation, confidence, and reduced anxiety are commonly reported benefits (Bailenson, 2022; Jones & Smith, 2023). Moreover, virtual tools help overcome barriers such as limited access to physical labs, geographical constraints, and high costs associated with consumables and equipment (Nguyen et al., 2022; Uwizeyimana et al., 2023). Challenges

include technological infrastructure deficits, digital literacy gaps among trainers and learners, and initial resistance to adopting new pedagogies (Ben Salem & Triki, 2023; Kamau & Mwangi, 2023). These issues are particularly pronounced in developing countries, where resource constraints limit widespread adoption. Despite this, incremental progress through pilot programs and donor support shows promise for scaling these innovations in Africa's TVET sector.

Methodology

The methodology for this study involved the use of secondary data collected from existing academic journals, books, government reports, and reputable online databases. The focus was on peer-reviewed articles and empirical studies published within the last five years to ensure relevance and currency. Data sources were systematically reviewed and selected based on their direct relevance to the use of simulations and virtual laboratories in TVET settings, particularly those addressing practical skills acquisition. The selected studies encompassed diverse geographical contexts, including developed, middle-income, and developing countries, to provide a comprehensive understanding of global trends and local experiences. The secondary data enabled the identification of common themes, methodologies, and findings related to the effectiveness, challenges, and impacts of virtual learning tools in vocational education.

A qualitative content analysis approach was employed to synthesize the information from the secondary data. Key variables such as the type of virtual tool used, the educational context, study designs, and reported outcomes were extracted and compared across studies. This method facilitated an in-depth examination of patterns and divergences in how simulations and virtual laboratories influence practical skills acquisition. Additionally, attention was paid to the methodological rigor of the source studies, including their sample sizes, data collection methods, and analytical techniques. The use of secondary data allowed for a broad and efficient investigation of the topic, circumventing the time and resource constraints of primary data collection while drawing on robust, validated research findings.

Findings

The findings revealed that the use of simulations and virtual laboratories significantly enhanced practical skills acquisition among TVET trainees across various contexts. Globally, studies indicated that virtual learning tools improved learner engagement, increased opportunities for repeated practice, and allowed safe experimentation without the risks associated with physical labs (Smith & Johnson, 2021; Lee et al., 2022). In developed economies such as Germany, Finland, and the UK, research showed that integrating high-fidelity simulations into TVET curricula led to measurable improvements in students' technical competencies and confidence (Müller & Weber, 2020; Virtanen et al., 2021; Brown & Davis, 2022). These studies typically employed quasi-experimental designs with control and intervention groups, using pre- and post-tests to assess skill levels, and reported statistically significant gains in practical performance.

In Sweden and Australia, findings also emphasized the role of virtual laboratories in bridging geographical barriers, especially in remote and rural areas, thus increasing access to quality technical education (Andersson & Karlsson, 2019; Thompson et al., 2023). Qualitative research in these contexts revealed that learners appreciated the flexibility and interactivity offered by virtual platforms, which contributed to higher motivation and reduced dropout rates. In middle-income countries like Egypt, Tunisia, and Ghana, studies demonstrated that while infrastructural challenges persisted, early adoption of simulations fostered improved understanding of complex technical concepts and boosted trainee readiness for real-world tasks (El-Sayed & Mahfouz, 2020; Ben Hassine, 2021; Owusu & Boateng, 2022). Mixed-method approaches predominated, combining surveys, interviews, and performance assessments, which collectively supported the positive impact of virtual tools despite resource limitations.

In developing countries such as Zimbabwe, Tanzania, Rwanda, and Kenya, although fewer studies were available, the findings were nonetheless promising. Research conducted in these settings highlighted that simulations and virtual laboratories helped compensate for shortages of physical equipment and trained instructors, thereby enabling more practical learning opportunities (Moyo & Chikoko, 2020; Mkude & Temu, 2021; Niyonkuru, 2022; Wanjiru & Otieno, 2023). The methodologies employed ranged from case studies to descriptive surveys, often relying on qualitative feedback and competency-based assessments. Kenyan studies, in particular, focused on the challenges of integrating virtual tools within existing TVET frameworks, pointing to issues such as limited internet access and lack of digital literacy among trainees and instructors. Nevertheless, these studies reported improvements in skill acquisition where virtual labs were effectively utilized, suggesting a growing recognition of their potential in enhancing vocational training outcomes (Kariuki & Mwangi, 2023; Odhiambo, 2024).

Conclusions

The study concluded that simulations and virtual laboratories play a crucial role in enhancing practical skills acquisition among TVET trainees across the world. The evidence from developed, middle-income, and developing countries consistently demonstrates that these virtual tools improve learner engagement, provide safe and repeatable practice environments, and increase accessibility to technical education. While developed economies benefit from advanced infrastructure and seamless integration of simulations into curricula, middle-income and developing countries face challenges related to limited resources, digital literacy, and infrastructural gaps. Nonetheless, even in resource-constrained settings, virtual laboratories have shown significant potential in supplementing traditional hands-on training and addressing equipment shortages.

Furthermore, the effectiveness of simulations and virtual labs is closely tied to the readiness of both learners and institutions to adopt digital technologies, highlighting the importance of targeted investments in infrastructure, training, and curriculum development. In Kenya, although studies remain limited, initial findings point toward a positive impact on practical skill development when virtual tools are incorporated effectively. This suggests that scaling up the use of simulations and virtual laboratories could substantially improve the quality and outcomes of TVET programs in the country.

Recommendations

i. There is a need to invest in robust digital infrastructure and reliable internet connectivity across TVET institutions, especially in developing regions, to facilitate seamless access to simulations and virtual laboratories.
ii. There is a need to provide comprehensive training and capacity-building programs for TVET instructors and trainees to improve digital literacy and ensure effective use of virtual learning tools.
iii. There is a need to integrate simulations and virtual laboratories systematically into TVET curricula, aligning them with practical learning outcomes and industry requirements.
iv. There is a need for policy frameworks and funding mechanisms that support the adoption, maintenance, and continuous improvement of virtual learning technologies in vocational education.
v. There is a need to conduct further research and monitoring to evaluate the long-term impact of simulations and virtual laboratories on skills acquisition and employment outcomes, particularly in under-researched contexts such as Kenya.

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