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## ARTIFICIAL INTELLIGENCE IN SIMULATION-BASED EDUCATION TRAINING FOR TVET: A MINI REVIEW OF BENEFITS AND LIMITATIONS

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### Abstract:

Purpose: This mini-review explores the role of Artificial Intelligence (AI) in simulation-based education for Technical and Vocational Education and Training (TVET), focusing on its benefits, limitations, and future directions. Its objective is to synthesize current research and identify opportunities and challenges associated with integrating AI technologies to enhance vocational learning. Methods: An inclusive literature review was conducted across articles indexed in the Scopus, Web of Science, and Google Scholar databases, using the keywords “artificial intelligence,” “simulation,” “education,” “TVET,” “benefits,” and “limitations.” Only English-language, peer-reviewed journal articles directly addressing AI in simulation-based TVET education were included, while grey literature and studies unrelated to AI were excluded. Results: The reviewed studies indicate that AI applications, such as Machine Learning (ML), smart training systems, and Virtual Reality (VR) or Augmented Reality (AR), enhance personalized learning, performance assessment, and skill acquisition. However, limitations such as high implementation costs, ethical concerns, concerns regarding data privacy and security and limited instructor preparedness persist. The literature also highlights ongoing debates regarding the balance between automated systems and human pedagogical guidance and inconsistent evidence regarding long-term

learning outcomes. Conclusion: Future research should prioritize developing standardized evaluation frameworks, conducting empirical studies with experimental designs, establishing ethical guidelines, and identifying cost-effective implementation strategies. Strengthening educators' digital literacy and promoting equitable access are vital to maximizing the pedagogical potential of AI-driven simulations in modernizing TVET training. Based on the findings, policymakers, government departments, and curriculum authorities are also encouraged to promote AI-driven simulation technologies as a foundation for modern TVET. This approach aims to prepare learners with the adaptive skills required for a rapidly evolving technological workforce.

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**Keyword:**

Artificial Intelligence; Simulation-Based Learning; Technical and Vocational Education and Training (TVET); Machine Learning; Virtual Reality; Digital Skill Development



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## Introduction

The rapid advancement of Artificial Intelligence (AI) is changing educational systems across disciplines, with particularly strong implications for Technical and Vocational Education and Training (TVET) worldwide. Prestoza et al. (2026) employed a hybrid model that combines AI tool assessments with human expert assessments. However, while AI tools enhance effectiveness, human assessors remain crucial for evaluating emotional intelligence, cultural factors, and decision-making criteria. Generative AI combined with Virtual Reality (VR) simulation, as studied by Zhang et al. (2026), holds significant potential to grow and provide relevant teaching exercises for Preservice Teachers (PSTs). These exercises are informed by experiences and observations of PSTs, as well as demonstrations of AI's usefulness in instructional simulations. The study presents the potential of generative AI simulation as a valuable tool for PSTs to practice digital skills with apparent authenticity, offering various teaching situations and reiteration exercises.

As industry progressively adopts intelligent automation and data-driven decision-making, TVET institutions face growing pressure to align their teaching and training methods with the skills required for the future workforce. This trend is evident in industries such as medical services, where AI adoption improves efficiency and decision-making. In contrast, a study by Liu et al. (2026) suggested that integrating a Large Language Model (LLM) into an educational agent-based simulation-instruction tool would deliver significant value in terms of practicability and instructional design quality.

The integration of AI into these simulations enhances interactivity, personalization, and performance assessment, making training more adaptive and immersive. This merging of AI and simulation-based education represents a timely and significant innovation for preparing students in technical fields to meet real-world professional demands. Within this framework, simulation-based education should allow learners to engage in a realistic, risk-free training environment, which has developed as a powerful instructional strategy. Despite these promising developments, the educational and ethical implications of AI-driven simulation in TVET remain underexplored and, in some fields, still debated.

While proponents emphasize its capacity to enhance skill development, motivation, and proficiency, critics raise concerns with regard to algorithmic bias, data privacy, overreliance on technology, and the possible loss of hands-on, practical involvement. Moreover, there is limited evidence that AI-based simulations translate into measurable improvements in vocational competencies compared with traditional training methods. In essence, these unresolved questions underscore the need for a stable examination of both the advantages and restrictions of AI-boosted simulation tools within the TVET context.

The primary aim of the mini-review is to synthesize current research on AI in simulation-based education for TVET, highlighting its technological foundations, pedagogical advantages, and associated challenges. The review identifies existing knowledge gaps in implementation practices, evaluation standards, and ethical frameworks in ensuring reasonable and effective adoption. It also explores various viewpoints within the academic community regarding AI's role as either an empowering educational tool or a potentially disruptive force in vocational learning. In particular, the discussion is structured around three key thematic areas: (1) the pedagogical and technological benefits of AI-driven simulations in the field of TVET; (2) the limitations with an ethical concern associated with their use; and (3) future research and policy directions to optimize their integration.

Overall, this review argues that while AI-enabled simulation holds great promise for transforming TVET into a more adaptive, industry-aligned educational model, its implementation requires careful ethical consideration. Thus, practical and didactic boundaries are necessary to ensure that technology enhances rather than replaces authentic vocational learning experiences.

### **Methods**

An inclusive literature search was conducted across the databases Scopus, Web of Science, and Google Scholar. The following keywords were used:

("artificial intelligence" AND education OR simulation-based AND TVET AND benefits OR limitations OR challenges OR advantages)

The search was conducted on 24<sup>th</sup> December 2025, and all applicable articles were retrieved. Numerous article types, including prior research, systematic reviews, meta-analyses, and case studies, were considered for this mini-review. This scoping search study covers the years 2021 to 2026, and all the articles cited were indexed in Scopus and Web of Science.

The following section outlines the inclusion and exclusion criteria applied in this review.

### ***Inclusion Criteria***

*Studies discussing various aspects of simulation-based education in TVET*

This inclusion highlighted that integrating realistic, interactive simulations enhances learners' technical competence, safety awareness, and problem-solving skills in TVET. An inclusive of 58 totally papers counted was review including existing PRIMA review paper.

The AssemVR environment, as a VR software, was developed to improve learning outcomes in Malaysian TVET institutions, as stated in the research (Nor Saradatul Akmar et al., 2026). This integration of technology could offer students practical experience, enhance skill development, and bridge the gap between academia and industry. Meanwhile, Tobias et al. (2024) in their research have highlighted that there are robust rules and technological integration in Germany and Malaysia that lead to higher female completion rates (100%). In contrast, in Mexico, lower rates (60%) are due to socio-cultural norms and limited digital infrastructure. The research also emphasizes the potential benefits and risks of AI and VR, including engagement enhancements and concerns about algorithmic gender biases. The new AI-driven technology is transforming industries by automating processes, improving decision-making, and nurturing innovation (Ishrat et al., 2025).

Mulders et al. (2024) described old-style training approaches as adequate for supporting the achievement of vocational competency. VR should be fully implemented to develop an inclusive learning environment with reliable training support. The crucial research finding indicates that this VR training is well-suited to support craftsmanship in automobile painting, which requires psychomotor skills and knowledge. In the new digital era, VR is emerging as a promising solution and has proven to be a powerful teaching model for developing competency, particularly in skills-based exercises (Mulders et al., 2024).

The passion for AR's employment across several modules and its potential to inspire and engage in the educational process has paved the way for instructional innovation. A study by Zuhairi et al. (2024) revealed that teaching aids empower teachers to refine their teaching approaches and achieve educational objectives effectively. In addition, the findings call for further investigation and the incorporation of AR technology into education. This emphasizes its potential to transform conventional learning environments into engaging, practical, and interactive experiences. Moreover, AR technology is widely believed to enhance inter-student collaboration among vocational institutions (Zuhairi et al., 2024).

An article by Zambri et al. (2022) on Augmented Reality (AR) in education reported that AR technology serves as an intervention that enables students to self-study, though not as a replacement for educators. Instead, it enhances pedagogical practices, enabling students to learn at their own pace, in their own time, and in their own place. The study has been conducted among instructors to gain their understanding and perspective on using AR technology in education and, at the same time, to raise students' motivation to learn.

Many scholars and educationalists suggest that using software kits and simulation systems (Stamenkovic et al., 2023) to demonstrate the algorithm's energy behavior would yield effective results. According to their study, students with no prior elementary knowledge may struggle to find resources when encountering complex, abstract AI algorithms.

Many authors agree that AI and simulation provide an effective bridge between theoretical knowledge and practical training, especially in TVET contexts where physical resources or industrial environments are not a part of the training.

### ***Studies Focusing on The Application of AI Tools In TVET Simulation Environments***

This inclusion further demonstrates the growing use of new educational technologies, such as adaptive learning, smart tutoring, and predictive analytics, to personalize training pathways and assess learner performance. Building on this, Machine Learning (ML) algorithms and AI-driven feedback systems have been proven to improve engagement, identify skill gaps, and optimize practice scenarios. Still, the degree of AI integration varies widely, with many implementations remaining at the prototype or pilot level.

Ishrat et al. (2025) stated that emerging trends in TVET education suggest that AI-driven tools can meaningfully enhance personalized education in line with supportive global sustainability goals. Furthermore, the integration of AI extends beyond improvements in instructional efficacy, as forces related to growth and sustainability are reshaping industry, society, and the economy. In this context, TVET education has become the connection between training and industry, aligning its framework with these emerging forces (Ishrat et al., 2025; Liow, 2025). In sync with the fast-changing technological landscape, the vocational center must implement adaptive, nimble plans. Hence, old-style instructional models must change to support lifelong education and continuous skill development to remain applicable in a challenging marketplace (Magagula & Awodiji, 2024).

Sustainability and AI embedded in TVET have nurtured an inclusive approach that successfully incorporates technological foundations, addresses frameworks, strategies, and best practices. It also explores the complexities and challenges associated with this transformation (Sorayyaei Azar et al., 2025). A study by Lim and Lee (2024) highlighted the need to rethink educational approaches in the era of AI to ensure future workforce competitiveness. In response, developing AI literacy and digital competency is crucial to fostering transformative educational strategies.

Furthermore, a recent study indicates that students from Malaysian Technical Universities (MTUN) are expected to develop 21st-century skills for the digital economy, including mastery of AI and Fourth Industrial Revolution (4IR), as well as leadership skills (Rosli et al., 2024). Therefore, in this digital era, AI applications and simulations are becoming increasingly meaningful in education and a general phenomenon.

### ***Analyzing Studies on The Strengths, Limitations, And Possible Applications of AI In Simulation-Based Education For TVET***

This criterion ensures consistent analysis of AI terminology across studies. For example, reports indicate that AI enhances accessibility, interactivity, and learning outcomes by enabling data-driven decision-making and individualized instruction.

In implementing potential AI simulation applications, students must also demonstrate strong technological readiness. As such, Mbambo and du Plessis (2025) reported that many students struggle with digital skills, making tasks such as editing and using online services that require digital competence particularly challenging. This study also evaluated the correlation between students' digital skills and their ultimate throughput rates.

In line with the National Policy on Industry 4.0, it aims to promote progressive technologies, such as AI. According to Mazlan et al. (2025), Industry 4.0 talent components for vocational students can be strengthened through Work-Based Learning (WBL) methods, which

encompass cognitive skills, operational work skills, individual skills, and professionalism. The study also identified 21 key components that further detail these skills and competencies, which are essential for prepared workers in the current AI-driven digital age.

In their analysis of strengths and limitations, Mittoor and Putteti (2025) underscored the value of projection models, smart automation, and progressive analytics. These approaches offer cost-effective, highly efficient ways to use resources. However, challenges such as ethical considerations and emerging guidelines for integrating AI and Big Data in TVET must be addressed to ensure sustainable and inclusive skills expansion and workforce readiness.

Solak Berigel et al. (2025) conducted a PRISMA-based Systematic Literature Review (SLR) to explore various methods for integrating AI into TVET systems. AI and Big Data have transformed instruction by enabling smarter, data-driven decisions through advanced tools, enabling seamless management of digital data, efficient performance analysis, and the design of impactful outcomes (Brass et al., 2023; Chen et al., 2024; Solak Berigel et al., 2025).

Hussein et al. (2024) revealed that adopting Enterprise Architecture (EA) is an effective strategy for TVET institutions to achieve a sustainable digital revolution, an essential strategy for preparing a workforce proficient in meeting current industrial demands. Their study explored the key factors necessary for the sustainable implementation of EA within Malaysia's TVET institutions, based on an SLR and a thematic analysis of stakeholder interviews. The findings indicated that eight key factors can be grouped into three main elements (process, people, and technology), as the factors of sustainable digital transformation. Within the technology element, the use of the Internet of Things (IoT) and AI has been emphasized as particularly crucial, as also noted by Bokolo et al. (2020).

A study by Fatokun and Gumbo (2024) reported the need to integrate emerging technologies such as AI and IoT into the electrical and electronics TVET curriculum to equip students with future-ready employability skills, given contemporary innovations. This study revealed a gap between technical understanding and the ability to address real-world challenges, underscoring the critical need for troubleshooting skills among new graduates.

Nevertheless, limitations such as high execution costs, data privacy concerns, insufficient standardization in evaluation frameworks, and imperfect teacher readiness remain the major barriers. Some studies also raise ethical questions about algorithmic bias, automation replacing human judgment, and overdependence on digital technologies.

### ***Studies Published in English***

This collective inclusion suggests that AI's potential in simulation-based TVET education is significant. Nonetheless, empirical evidence supporting its long-term effectiveness and the transferability of skills to real-world work settings remains limited and is based on English-language articles, journals, and papers.

## Exclusion Criteria

### *Studies Published in Languages Other Than English Were Excluded*

To maintain consistency and ensure accessibility of interpretation, only English-language publications were considered for this review.

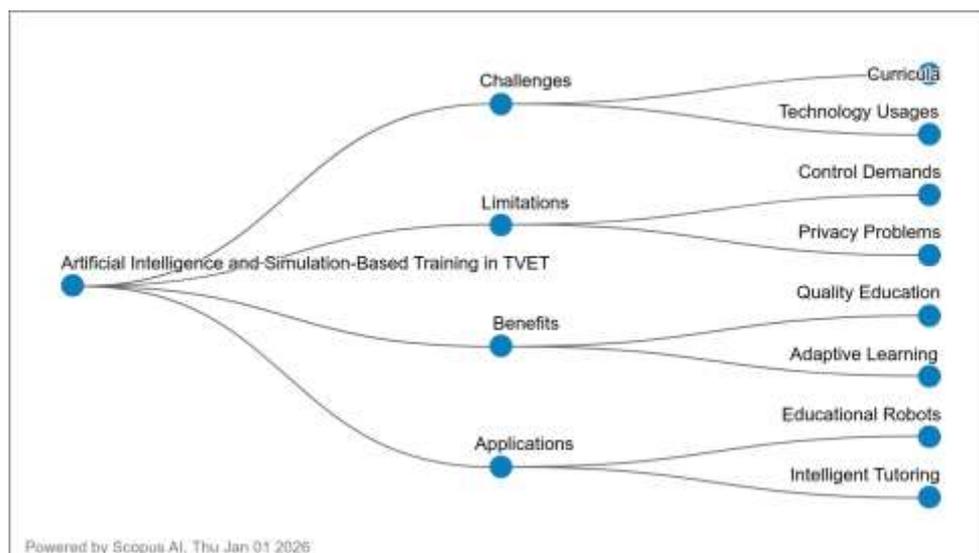
### *Studies That Discussed Simulation-Based Education or TVET Without Explicit Reference to Artificial Intelligence Were Excluded*

This criterion ensured that all included studies directly addressed the integration, application, or evaluation of AI within simulation-based educational contexts in TVET.

### *Grey Literature (Conference Abstracts, Unpublished Reports, Articles in Press) Was Excluded*

Only peer-reviewed journal articles were involved to increase the reliability, credibility, and scholarly quality of the analysis findings.

## Discussion and Result



**Figure 1: Concept Map generated by Scopus AI, Date on 1<sup>st</sup> January 2026**

Based on Figure 1, AI and simulation-based training in TVET comprises four component clusters, which are the main focus of the application theme. The second discussion focuses on benefits, and the third on limitations, with additional challenges that may arise in this mini-review. Figure 1 illustrates the concept map generated by Scopus AI on 1<sup>st</sup> January 2026.

In the study of AI integration in TVET Education, there is greater discussion of personalized learning practices, such as familiarizing content and increasing technology use. Moreover, there are discussions about how AI tools enable more efficient assessment and about AI-driven virtual simulations in VR and AR as immersive learning experiences. Additionally, discussions address real-time support and guidance through intelligent AI simulation, as well as managerial support focusing on teaching delivery and student responses.

Adaptive learning and quality education are the benefits that result from the use of AI and simulation in TVET education, as demonstrated in Figure 1. In this part of the discussion, there is an elaboration on how AI tools assist and enhance engagement, improve the learning outcomes in education, and raise competency. In this digital era, the effectiveness and availability of AI-driven tools are essential to the learning system. Nowadays, AI and Big Data analysis are tools for optimizing resources, an essential part of profit discussions.

Subsequently, there is still discussion around the limitations and challenges of AI and simulation in TVET learning. Following this, elements of data privacy and security need to be verified as they concern the usability of AI technology. In this context, the AI system could also propagate biases and raise ethical concerns if improperly managed. Conversely, challenges may occur due to a lack of technical training for lecturers, insufficient funding, and insufficient infrastructure. When over-reliance on technology, such as AI, is used in a simulation approach, it leads to less human communication, such as empathy and adaptability. In addition, algorithmic limitations, incomplete algorithm design, and a lack of labelled data can limit the effectiveness of AI applications.

### ***Artificial Intelligence in Simulation-Based Education for TVET based on the theme Application***

Nowadays, AI is increasingly transforming simulation-based education in TVET, offering dynamic, adaptive, and data-driven education practices. AI applications such as smart tutoring systems, predictive analytics, and virtual simulations are being integrated to personalize instruction, enhance engagement, and safely and efficiently replicate complex industrial processes. Current developments demonstrate AI's potential to strengthen learners' problem-solving, decision-making, and technical competencies. This is achieved through realistic, feedback-driven environments.

According to Solak Berigel et al. (2025), AI applications across advanced, ethical, and legal dimensions have become significant points of discussion. Meanwhile, Guttha et al. (2025) explored the combination of AI and ML across numerous fields, primarily healthcare, agriculture, and smart systems. This integration has attracted significant attention in recent years by transforming healthcare applications through process restructuring, improved decision-making, and refined patient outcomes. In drug commercial applications, AI-driven tools are being used in drug discovery, optimizing clinical trials, forecasting patient feedback, and confirming regulatory approval. TVET is now playing a crucial role in developing healthcare specialists, technicians, and supervisory expertise for AI-driven innovations in the pharmaceutical and biotechnology sectors (Guttha et al., 2025).

The United Nations endorsed the application of AI in TVET education in 2015 as part of the Sustainable Development Goals (SDGs) (Omeh et al., 2025; Qadir et al., 2023; Ryan et al., 2019). In particular, SDG4 was highlighted for its comprehensive and equitable approach to education, elevating lifelong learning opportunities and serving as a standard (Putra et al., 2023). Subsequently, Callahan et al. (2021) and Vázquez-Parra et al. (2024) stated that, in terms of the perceived value of AI training, this integration in education has significantly increased awareness of its latent consequences for instruction and educational practices, as well as the acceptance of AI applications.

In other applications, new AI-driven tools such as VocScholar use dynamic taxonomy mapping to enhance the relevance of vocational research explorations (Rama et al., 2025). This study introduced VocScholar as a platform tailored to advance the discoverability and relevance of vocational research literature, supporting evidence-based practice and policy in TVET. In addition, Fombona et al. (2025) elucidated that AI is driving a new educational paradigm by enabling the expansion of adaptive learning structures and adapted support. It derives from a study of expressive methodology based on a systematic review of 132 articles from the Web of Science database from 2020 to 2023, selected using the PRISMA procedure and prioritizing peer-reviewed studies on AI, automation, and teaching. This study also examined the possible effects of changing the instructor's duties and adopting a conventional teaching approach. According to the findings, policymakers have a responsibility to design tools to address the essential needs of the educational system, including effective governance frameworks and the technological infrastructure required (Fombona et al., 2025).

However, challenges persist, including high implementation costs, limited infrastructure in developing regions, data confidentiality concerns, and the necessity for educator training in AI pedagogy. Despite these barriers, emerging technologies such as AR, VR, ML, and Natural Language Processing (NLP) are expanding the scope of simulation-based education.

The integration of new technology is shifting the way learners study and educators teach. With the rapid adoption of AI and robotics, significant challenges arise regarding data privacy, equitable access, and the sustainability of their operations across disparate educational settings. Notably, there is a need to analyze AI technology in its applications, focusing on the social, ethical, and pedagogical aspects of its incorporation into educational systems (Fombona et al., 2025; García-Peñalvo, 2024). Building on this, AI integration has introduced several AI application software tools, including Gradescope, which provides automated scoring and feedback, and Coursera, which uses AI for virtual instruction. Other applications include Squirrel AI, which offers AI-based adaptive learning, and Watson Tutor, an educational chatbot designed to advance independent learning (Yufeia et al., 2020).

In addition, NLP has motivated the development of instructional chatbots and virtual assistants that optimize learners' interfaces and offer real-time responses. For example, software such as ChatGPT and Watson Aides has demonstrated its capability to respond to queries, produce tailored explanations, and encourage self-directed learning (Fombona et al., 2025; Gligorea et al., 2023; Okagbue et al., 2023). With the progression, AI continues to change the landscape of education, particularly in the openness and personalization of learning enabled by digital technology.

A study identified that integrating AR and VR into educational environments meaningfully enhanced student communication by merging immersive technologies with AI algorithms (Hwang & Chu, 2023). As such, these tools enable the simulation of energetic learning environments, strengthening understanding of abstract ideas through interactive engagement.

Future directions emphasize interdisciplinary collaboration to develop ethical frameworks, standardize evaluation methods, and ensure equitable access to AI-enhanced training tools. While debates continue regarding the balance between automation and human instruction, indications suggest AI can complement rather than replace educators by facilitating more effective, learner-centered environments. Thus, addressing gaps in longitudinal outcomes and

ethical governance would be critical for optimizing the potential of AI-driven simulations to modernize TVET and prepare learners for the emerging demands of Industry 4.0.

### ***Artificial Intelligence in Simulation-Based Education for TVET based on Benefits***

AI in simulation-based education for TVET offers significant benefits. It creates adaptive, interactive, and learner-centered environments that closely replicate real-world technical scenarios. AI-driven simulations enhance personalized learning, immediate feedback, and performance tracking, enabling students to develop practical skills safely and efficiently. Key technologies widely used, such as ML, NLP, and VR or AR, when modernized, could support intelligent tutoring, predictive assessment, and scenario adaptation, thereby improving competency-based education as envisioned.

Wong and Abdullah (2025) conducted an empirical study and observed that job readiness among electrical and electronics TVET students is a critical factor in meeting Industry 4.0 demands. According to their study, robust technical education is critical for fostering job readiness in this new era. Reasoning and problem-solving were identified as crucial skills by 69.2% of respondents. Correspondingly, these cognitive abilities enable people to address complex challenges and become familiar with the embryonic demands of the modern job marketplace (Kamaruddin & Rasdi, 2021). Hence, integrating these skills into education has prepared students to meet industry requirements and boosted their employability (Wong & Abdullah, 2025). Moreover, AI offers significant potential for reducing workload (Hong & Kim, 2024; Jamil et al., 2024; Solak Berigel et al., 2025). The effectiveness of AI tools in ensuring fair and accessible learning depends on a person's preferences. This research focuses on the readiness of TVET graduates for the new era of digitalization, with the ability to use AI technologies in their practical, hands-on skills to pursue career opportunities.

Research studies by LeClair et al. (2023), Nadzinski et al. (2023), Petridou and Lao (2024), and Samarasekera et al. (2024) revealed that modern curriculum development must prioritize digital literacy and adaptive learning technologies, which are strengthened by AI, data science, and deep learning among students. Developed countries were conducting Research and Development (R&D) activities with TVET graduates in production development processes, using AI tools more intensively in their educational curricula (Rigley et al., 2024). Elevating the curriculum with AI tools, ensuring a satisfactory level of education for trainer managers and stakeholders in AI-based training, and updating the existing curriculum accordingly are prominent methods (Solak Berigel et al., 2025; Yadav & Shrawankar, 2025).

In another study, Dahuri et al. (2025) conducted a bibliometric exploration that demonstrated the critical role of building condition assessments in determining maintenance strategies for TVET institutions. This enables the digitalization and modernization of their infrastructure management systems. Moreover, in another study, AI-based microcredentials and digital certifications enable workers to acquire new competencies in an elastic, accessible manner (Shanmughan et al., 2024).

Furthermore, in a labour market that keeps pace with rapid technological progress, there is demand for upskilled workforces. Supporters identified significant challenges in Information and Communication Technology (ICT) infrastructure and cybersecurity, while emphasizing a knowledge gap in how AI facilitates value formation in TVET programs. Consequently,

integrating ICT into vocational education is required to contribute effectively to the SDGs (Badawi & Drăgoicea, 2023).

Despite these advantages, challenges remain in various perspectives, including high costs, technological inequalities, ethical concerns, and limited instructor preparedness. Ongoing debates focus on balancing automation with human guidance and confirming reasonable access to AI tools. The gaps that persist in evaluating long-term learning outcomes, cross-disciplinary integration, and the ethical governance of AI applications are also being discussed.

Hassan et al. (2021) conducted an SLR to investigate the use of ICT as an enabled function in TVET programs that require it as a role in TVET pedagogy, training transfer, educators' training, curriculum, and labs to address new-era challenges. The study identified that ICT technologies and applications are spreading into the TVET training sequence system. However, their implementation remains limited, primarily in areas such as nursing and assessment, career direction and job placement, trainee valuation, and educator training. It is recommended that government bodies further explore IoT, Robotics, Data Science, AI, cloud computing, and related technologies across all TVET training programs. This approach aligns with industry demands, as knowledge economies have increased the need for an educated and digitally skilled labour force (Hassan et al., 2021).

Future directions emphasize developing standardized assessment frameworks, promoting digital literacy among educators, and fostering collaborations between academia and industry to enhance the scalability of AI-driven simulations. For example, Younis (2025) developed a new framework for vocational education that integrates technology, pedagogy, and work content knowledge in entrepreneurship, known as the Critical Competency Attributes / Technological Pedagogical Content Knowledge (CTA/PEWCK) model. This model integrates AI technology (ChatGPT) with an in-depth literature review to explore the knowledge dimensions of professional teaching and ICT. As such, the findings have revealed 15 knowledge dimensions for TVET teachers, focusing on practical experiences to develop capabilities for sustainable development. This, in turn, brings new benefits to TVET programs and outcomes.

SDG 4 is a United Nations commitment to ensuring comprehensive and equitable quality education and promoting lifelong learning opportunities for all, with a target of 2030. Cowin et al. (2024) highlighted how AI coaching and simulation-based training can accelerate learning transformation in higher education. In their study, they explored shifting education paradigms in higher education using software such as simSchool and Mursion simulation platforms to develop skills and abilities in a controlled space of experimentation (Cowin et al., 2024). Therefore, simulation-based training, when integrated with AI, provides a solution-oriented approach to prepare teachers with the required skills and proficiencies to navigate the complex, real-world education in this digital era.

Overall, while limitations exist, the incorporation of AI into simulation-based TVET education represents a transformative step toward modernizing skill training and bridging the gap between theoretical knowledge and industrial practice. It also prepares learners for the demands of rapidly evolving technological workplaces.

## ***Artificial Intelligence in Simulation-Based Education for TVET from a Limitations Perspective***

Despite its potential, the incorporation of AI into simulation-based education for TVET still faces several limitations that would delay its widespread and equitable adoption. Key challenges include high operational costs, deficient digital facilities, a lack of standardized frameworks, and limited instructor or lecturer readiness to use AI-enhanced tools effectively. Ethical issues, such as data privacy, algorithmic bias, and overreliance on automation, further complicate its deployment in educational settings.

A study revealed that TVET instructors agreed that AI technology is an effective educational tool (Omeh et al., 2025). However, there is a need for ethical principles to ensure that data privacy, integrity, reliability, transparency, and accuracy are not compromised. In this study, instructors have doubts with regard to ethical procedures for overseeing AI and need clarification on the data security involved. The integration of AI technology into TVET institutional training also requires a strong ethical policy framework and data privacy policies, with consequences for curriculum developers to produce acceptable syllabuses that allow the acceptance and use of AI in the execution of a diversity of instructional methods (Omeh et al., 2025).

Varsik and Vosberg (2024) stated in their study that AI and robotics in the educational system are developed and present significant challenges and limitations, predominantly in relation to the digital gap and instructional fairness. As a limitation, this recent study suggests that access to AI platforms remains contingent on socioeconomic and topographical factors, which could exacerbate disparities in data access.

In addition, while all AI technologies, such as VR and AR, have indicated promise in enhancing realism, personalization, and assessment accuracy, their integration often remains fragmented and experimental. Thus, education in this field now promotes significant advancements despite existing limitations in ethical principles and legal frameworks (Hu, 2022; Ossa et al., 2023; Solak Berigel et al., 2025; Vázquez-Parra et al., 2024). Therefore, the policymaker's role is essential in controlling the area involved in procedures or best-practice rules.

The study by Olabiyi and Chinedu (2025) identified the integration of AI and vocational pedagogy in formative labour development. It was revealed that vocational pedagogy affects skills development through the incorporation of technology in TVET, with an AI-driven labour revolution in Nigeria, though it also has limitations. Following this, educators face apparent challenges in implementing AI and in leveraging its benefits to develop learners' AI skills.

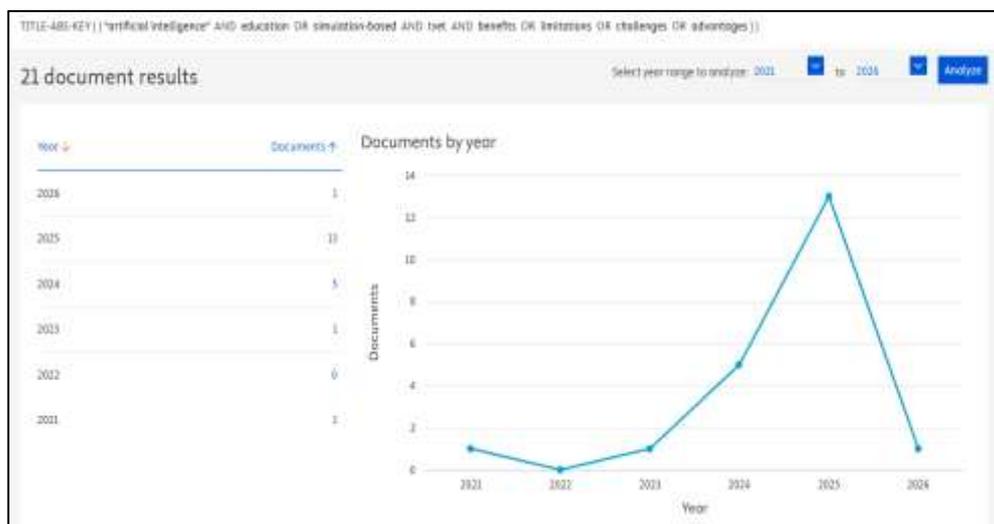
Meanwhile, areas of study such as educational robotics lack a comprehensive theoretical framework, underscoring the need for organized revisions to identify trends and gaps in the AI education literature (Uslu et al., 2022). Moreover, deficiencies in the pedagogical methods setting and the lack of systematic evaluation of the real impact of AI on pedagogy have created uncertainty about the long-term effectiveness (Meylani, 2024). In evaluating training and education processes (Zawacki-Richter et al., 2019), the study observed that they are fragmented and lack a unified framework for AI and robotics applications in teaching, raising challenges and unfamiliar areas that require further analysis.

Alternative key issues include the growth of generative AI and educational robotic systems, alongside heated debates about their implications for education. The current study has emphasized the role of automation, rather than AI, in improving the value of studies in this specialization area (Tomczyk et al., 2024).

Debates continue over whether AI should be used as a supplement or as a replacement for human instructors, particularly in skill-based learning environments that rely on hands-on experience. Still, significant gaps persist in empirical research evaluating long-term learning outcomes, cost-effectiveness, and inclusivity. In response, future directions call for comprehensive policies that support ethical governance, educator capacity building, and collaborative frameworks between industry and academia to ensure sustainable implementation. Thus, addressing these limitations through inclusive design and evidence-based practice is crucial for maximizing the pedagogical and practical potential of AI-driven simulations. Such approaches help TVET learners acquire AI and simulation skills and build resilience for advanced workplace qualifications.

### ***Graph Analysis from Scopus AI***

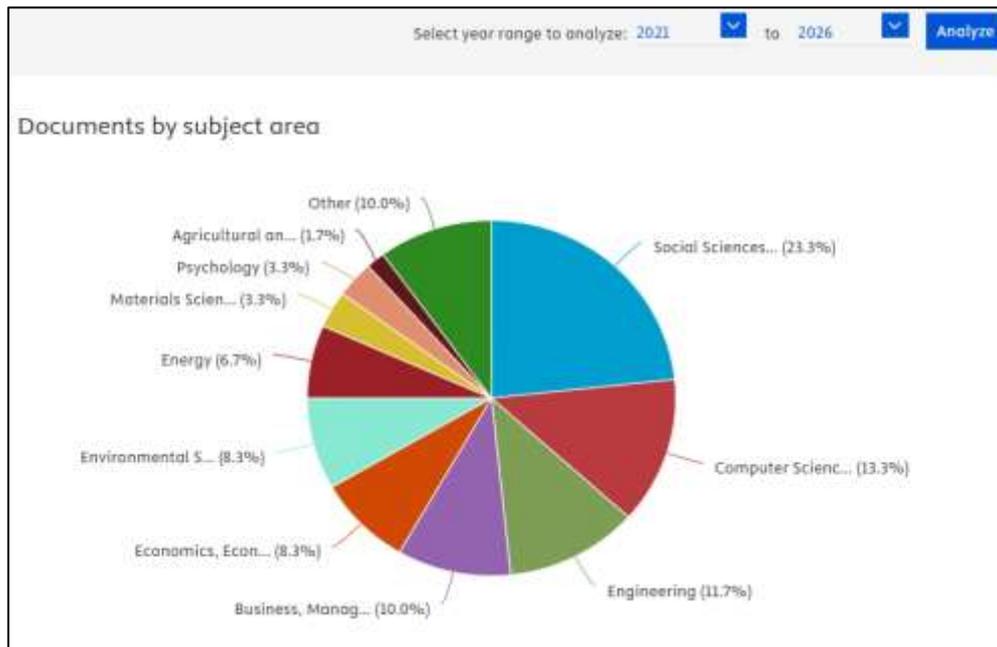
The following keywords were used in Scopus AI;  
**("artificial intelligence" AND education OR simulation-based AND TVET AND benefits OR limitations OR challenges OR advantages)**



**Figure 2: Graph generated by SCOPUS on 26<sup>th</sup> December 2025**

Based on Figure 2, 21 documents have been discussed in this mini review from 2021 to 2026. However, there are also additional articles that have already been discussed in the document, such as the SLR of 73 papers from a paper study by Solak Berigel et al. (2025). Another review by Fombona et al. (2025) evaluated 132 articles from the Scopus and Web of Science databases, summarizing high-quality studies in a cluster of AI applications and simulation-based education. The key elements of each paper were analyzed to assess and summarize the main points of the mini review, including significant discussion, all of which have been properly cited. As illustrated in the graph, the number of documents published per year demonstrates an increasing trend, peaking in 2025 at 13. In 2026, only one document has been published thus far, as data are current up to the first week of January. In this context, the increasing number of

publications on AI and simulation technology reflects a growing priority, aligning with the digital era and the widespread familiarity with AI tools across all fields of study.



**Figure 3: Pie Chart generated by SCOPUS on 26<sup>th</sup> December 2025**

Based on Figure 3, this mini-review has 3 main clusters of documents by subject area: Social Sciences (23.3%), Computer Sciences (13.3%), and Engineering (11.7%), all still in the domain of education. With these three main clusters apparent in TVET education technology, they had an impact on this mini-review study in various ways and issues. Other than that, there are small portions of business management, economics, environmental studies, energy, materials sciences, agriculture, psychology, and others, which together cover almost half of the pie chart.

### Conclusion

In summary, this mini-review highlights that AI has been a revolutionary tool in simulation-based education for TVET training, offering improved interactivity, personalized learning, and more effective performance assessment. The deployment of AI, along with technologies such as ML, smart tutoring, and VR clusters, has enabled learners to participate in realistic, domain- and adaptive training environments. These environments effectively bridge theoretical knowledge and practical skills. However, significant limitations remain, including high operational costs, ethical concerns over data privacy and bias, insufficient digital infrastructure and access, and limited educator readiness. Ongoing debates persist over the balance between AI automation and human coaching, as well as the effectiveness or long-term impact of AI-driven training on employability. Therefore, future studies should focus on emerging standardized assessment frameworks, empirical experimental studies, ethical governance models, and cost-effective implementation strategies. Accordingly, strengthening instructor-led exercises, fostering interdisciplinary collaboration, and ensuring reasonable access to AI tools will be essential to maximizing this technology's pedagogical potential. The findings suggest that policymakers and curriculum authorities should consider structured frameworks for integrating AI-driven simulation technologies as a foundation for modern TVET. This suggestion could also prepare learners with the adaptive skills required for a rapidly evolving technological workforce. These findings align with contemporary digital pedagogy

frameworks and Technology Acceptance Model (TAM) that emphasizing adaptive feedback and experiential learning. By focusing specifically on AI-driven simulation within TVET contexts, this review addresses a gap in synthesizing evidence on vocational skill acquisition rather than general higher education settings.

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