

Transforming TVET with AI: Economic Benefits of Technological Innovation in Education

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Abstract

TVET is indispensable for building up the skilled human capital which is vital for the competitiveness of the economy and enhancing social cohesion. This systematic review focuses on the adoption of AI in TVET to assess its potential to revolutionize the sector and contribute to economic development. The research includes identification of the key academic databases containing articles and papers relevant to the AI in TVET, and emphasis on the recent publications. This is in line with the key findings highlighted above in sections on; Personalisation in learning. Administrative automation in institutions, AI and Industry needs at TAFE Queensland and Nanyang Polytechnic institutions. The review finds that AI in TVET positively impacts employment prospects, alleviates costs, and fosters innovations, implying that coordinated partnerships and policies should be pursued to optimise the AI benefits and contribute to sustainable economic development.

1. Introduction

TVET is crucial in the formation of skilled human capital, without which no country can develop its economy and become competitive. TVET educates learners to acquire knowledge and skills relevant to a certain job sector, therefore increasing their chances in the job market (UNESCO, 2021). It is useful in filling the skills gap in the labor market, eradicating unemployment and promoting inclusion for the less privileged in society (Tahirović et al., 2022). In this age of technological advancement, incorporation of AI in TVET is a challenge that offers the potential of improving these programs even more.

AI technologies such as machine learning, natural language processing, and robotics have the capacity to transform educational processes. Another benefit of implementing AI is the possibility of delivering content in an adjusted manner based on proficiency levels, thereby raising the chances of success in the classroom (Katiyar et al., 2024). In addition, AI can also minimize bureaucracy, and this assist the educators in the teaching and coaching; intelligent and personal tutors that assist the student with feedback and support in an intelligent manner (Alam, 2023). The use of AI in TVET is particularly relevant because there are opportunities to increase the relevance of the training programs and provide students with qualifications that would be competitive in the job market.

In this regard, this systematic literature review aims at identifying how AI has impacted on TVET, and the economic benefits associated with incorporating AI & technology in the design of these TVET programs. Specifically, this review will seek to determine how contemporary AI technologies are being applied in TVET, identify best performing use cases and practices across the regions and examine the economic implications of these innovations. Based on how AI has been incorporated into TVET in this review, it will also be easier to see how AI impacts on positive labor market outcomes, reduces costs of education and efficiently determines the appropriate resources thus realizing more value for money in investment towards education.

In addition, the review discusses the social impact of AI as it relates to innovation, productivity and competitiveness of sectors involved in TVET. Consequently, potential macroeconomic goals, such as the generation of the long-term economic impact in terms of employment opportunities, the emergence of new industries and sectors, and the sustainable economic development goal are considered (Mohammad et al., 2024). AI integration in TVET can help immensely in economic development if it leads to the production of manpower that can embrace and supporting advancement in technology.

The arrangement of this paper is partitioned into several sections and subsections. The section on ‘methodology’ describes the approach to literature searching and selection of articles, and the criteria used for screening and analysis of data. This section goes deeper into AI and technology in TVET, the economic opportunities available from the innovations, and lastly, the limitations and factors to consider while adopting them. Consequently, the paper includes a conclusion regarding future research, specific recommendations for stakeholders, and an overview of the study’s research findings. Thus, by offering an overview of how AI has reshaped TVET based on the current literature, this paper hopes to provide practical guidance for educators, policymakers, and CEOs interested in using AI to improve economic growth and competitiveness.

2. Methodology

The approach used in this systematic review was that of a systematic and rigorous search of the literature to obtain works that addressed the role of AI in transforming TVET and its economic value. The study was performed using several primary academic databases, such as Scopus, Google Scholar, IEEE Xplore, and PubMed, with emphasis on the materials published during the last five years. Also, there were use of institutional repositories and digital libraries of UNESCO and OECD.

Search Strategy:

- **Keywords:** AI in TVET, Artificial intelligence and vocation education, Economic implication of AI in education, Technological advancement in TVET, Technological advancement of education and economic development.
- **Inclusion Criteria:** Empirical and theoretical articles from peer-reviewed academic journals, proceedings of recent conferences and workshops, real-life cases, and reports from reputable organizations and institutes with preference towards articles published in the last five years.
- **Exclusion Criteria:** The articles that have been excluded from the review based on certain criteria or not related to the focal areas of the review.

Data Extraction and Synthesis: To conduct data extraction systematically, a Prescribed Data Extraction Form was used to extract information concerning study aim and objectives, methods, type of AI technology used, results, and costs involved from each of the selected studies. The data synthesis employed thematic analysis to identify and interpret key themes within the qualitative data, organized into coherent themes and sub-themes, presented through tables and charts where applicable.

Systematic Literature Review (SLR) Method:

The SLR method was elaborated by systematically identifying, evaluating, and synthesizing the findings from selected studies to address the research questions comprehensively. Table 1 provides a clear estimate of the SLR method, ensuring transparency and rigor in the systematic review process.

Table 1 SLR breakdown table

| Section | Description |
|--------------------|---|
| Research Questions | Key questions guiding the review |
| Search Strategy | Databases, keywords, and inclusion/exclusion criteria |
| Data Extraction | Standardized form for gathering study information |
| Thematic Analysis | Identification and interpretation of key themes |
| Data Synthesis | Summarizing findings and drawing comparisons |
| Visualization | Tables and charts to present synthesized information |

3. AI and Technological Innovations in TVET

It is important to note that AI technologies are rapidly revolutionizing TVET program delivery, learning experiences, and education’s relevance to the industry. This systematic review reviews machine learning, natural language processing and computer vision in TVET, illustrating how learning management systems, ITS and Ai

enhanced learning platforms like Coursera and Khan Academy enhance efficiency and efficacy. Also, AI applications in industries like welding, manufacturing, and hospitality showcase immense progress in skill enhancement and performance optimization. Thus, this review of case studies and research supports the proposition and necessity of utilizing AI for curriculum enhancement, learning personalization, and skill authentication in the context of TVET towards promoting lifelong learning and addressing the growing demand for skilled labour in the current and emerging job market.

AI technologies are revolutionizing TVET programs by improving learning and teaching process and making education more relevant to the occupations market. This review reflects on how machine learning, NLP, and computer vision can be applied in attaining the objectives of TVET and supporting how intelligent adaptive learning systems, ITSs, and AI-based platforms such as Coursera and Khan Academy individualize learning and enhance learner performance.

3.1 Key AI Technologies in TVET

AI technologies are in the process of changing the education paradigms, greatly improving the prospects of TVET programs.

The major AI techniques are ML, NLP and CV.

- Machine Learning = Supports contextual learning systems for individual approach in working with students using data on their performances.
- Natural Language Processing (NLP) = Crucial to ITS, auto-proctoring tools and messaging bots that respond to students' inquiries in real-time.
- Computer Vision = Beneficial in training courses such as manufacturing and especially in the medical education field by increasing accuracy and offering lab simulation trials.

Applications and Innovations = Technological advancements in artificial intelligence (AI) have positively impacted on TVET through such innovations as; intelligent tutoring systems, virtual/augmented reality and AI learning management systems (LMS). For instance, VR and AR provide training in realistic simulations, and AI incorporated LMS apply big data analysis for detecting learners at risk of falling behind and managing routine administrative work.

Enhancing Curriculum and Learning Outcomes = AI supports or assists educators in the development of elaborate curricula by forecasting the demand for specific skills in a certain field on the labor market. AI systems receive the information about the learner's learning style and the pace, which in turn helps to make personalization of the process. AI tools also provide objective and consistent skill assessments through simulations and automated grading systems, ensuring fair evaluations.

Computer vision technologies enhance TVET fields such as manufacturing and medical training. In manufacturing, ML object detection algorithms improve training accuracy and feedback (Chandrasekar, 2022). In mechatronics education, prototypes like the "ball and plate" system teach control algorithms through practical experimentation (Wu et al., 2023). Integrating computer vision in TVET, especially through blended learning, enriches educational experiences, crucial during challenges like the COVID-19 pandemic (Hashim & Hamidon, 2022).

AI-driven platforms like Coursera, Udacity, and Khan Academy personalize learning paths, recommend resources, and provide real-time feedback in TVET (Mese, 2023; Tapalova & Zhiyenbayeva, 2022; Onyango & Kelonye, 2022). These platforms use AI algorithms to adapt to individual learning styles and progress, offering tailored content (Niu et al., 2022; Alam, 2023). AI-driven chatbots enhance engagement by facilitating real-time interactions and instant feedback during online sessions. Incorporating AI in TVET creates immersive virtual environments, tracks learner performance, and provides personalized recommendations, improving concept mastery in technical and vocational fields.

3.2 Applications and Innovations in TVET

AI-driven tools have revolutionized TVET by introducing intelligent tutoring systems (ITS), virtual and augmented reality (VR/AR), and AI-powered learning management systems (LMS). ITS like Carnegie Learning's math tutoring systems adapt instructional materials to learners' needs, enhancing teaching effectiveness (Koedinger & Corbett, 2016). VR and AR create immersive training environments in fields like automotive repair, healthcare, and aviation, allowing risk-free practice of practical skills (Johnson et al., 2020). Due to the features such as predictive analysis to detect struggling learners and the automation of tasks, it shows that the use of intelligent LMS like Moodle and Blackboard can enhance efficiency and the delivery of education (Dawson et al., 2019).

Solutions within innovative practices of TVET prove AI's a revolutionizing factor in welding, manufacturing, and hospitality industries. The use of artificial intelligence improves teaching, learning, and job quality in TVET institutions (Onyango & Kelonye, 2022; Milanez, 2023). AI technologies have also enhanced the teaching of English

in vocational colleges and has been efficient in the integration of English into the teaching curriculum (Wu, 2022). Engagement of private sector in TVET is important to produce employment-ready graduates as well as to improve efficiency and productivity of employees in the workforce (Stephen, 2022).

In welding programs, ANN, DNN, and CNN play an essential role in enhancing the training process by forecasting the quality of the welded arc and the width of the bead (Kim et al., 2023). Manufacturing Industry-Specific AI-Based Predictive Maintenance Training increases operational effectiveness utilizing diagnosis in real-time (Ringler et al., 2023). The use of AI integrated language learning systems for employees in the hospitality industry offers insights of maintenance needs for improved skill enhancement and productivity (Plathottam et al., 2023). These developments point to the fact that AI is a revolutionary tool for strengthening skills and optimizing processes in different fields.

3.3 Enhancing Curriculum and Learning Outcomes

AI also helps to improve curriculum development, differentiation and assessment in skills taught in the TVET system. The same way, AI assists educators in establishing evolving curricula considering various professions and expected future demands (Shiohira, 2021). Flipped classroom systems that use artificial intelligence to identify students who learn differently and at different speeds improve engagement leading to high student retention (Holmes et al., 2019). A site like Smart Sparrow involves the use of adaptive learning technologies to enhance student performance (Kerr, 2016). AI tools also offer credible and unbiased performance evaluations through simulations and automated grading systems because the machine does not favor any group of students (Zawacki-Richter et al., 2019). Digital tools such as Gradescope also help in grading as they open up opportunities for instant feedback relieving educators of the burden (Saliba et al., 2024).

Concisely, the findings highlight that AI and technological advancements apply a significant impact on TVET by improving the modes of teaching, closing the skills divide, and promoting continuous learning. Consequently, AI supports face-to-face and online learning in students, assists in understanding their learning patterns, and shapes TVET programs according to the labor market demands to meet the industries' needs (Brynjolfsson & McAfee, 2014). AI can also facilitate on-going learning to ensure that the professionals are always ready to meet the changing market demands (Maity, 2019). AI-enabled micro-credentialing platforms such as Credly enable continual learning by enabling knowledge perimeter assertion in a highly portable and distinct manner (Carey, 2016, Muilenburg, 2016).

4. The Transformative Impact of AI on TVET

The incorporation of artificial intelligence in the TVET programs promises to bring about a revolution in the economic as well as the education structures globally. In terms of promoting the competitiveness of the Human Capital by driving economic growth and adapting the concept of cost-effective learning that is optimized through the use of AI tools and platforms. Thus, it not only enhances the rate of acquiring necessary skills but also guarantees compliance with the requirements of the labor market. In addition, AI enhances learning through immersive technologies such as Virtual Reality and Augmented Reality, enhances output through automation of time-consuming and mundane tasks, and catalyzes creativity through effort of entrepreneurial mind set. The adoption of AI in the countries' TVET system improves how the countries transition to a more ready, skilled, and effective workforce to support the fourth industrial revolution.

4.1 Economic Benefits of AI in TVET

The application of AI in TVET programmes has important economic opportunities that improve the TVET programs have significant economic values based on the utilization of AI that enhances workforce productivity, fosters economic growth, and maximize cost and effectiveness. The delivery of AI assists in competency development by offering individualized instructional content and thus improving the learning process (Maghsudi et al., 2021). The learning technologies can identify a students' performance profile and then help learners learn more effectively (Liu et al., 2023). These AI tools assist in the market relevance of these TVET programs, whereby information on the trends in the labor market and anticipated demand for specific skills is harnessed to modify curricula where needed (Brasse et al., 2024).

AI also allows for realistic hands-on practical experience through Virtual Reality (VR) and Augmented Reality (AR). These technologies afford the students a chance to exercise technical inputs, which are important in organizations that require accuracy and control (Gavish et al., 2015). Virtual learning contexts resemble real ones and allow students to work under real-life situations that cannot be practiced in a physical environment (Hernandez-de-Menendez et al., 2020). They reason that this training enhances the students' employment prospects and marketability.

4.2 Boosting Innovation and Entrepreneurship

Moreover, it optimizes responsibilities like grading and scheduling tasks to save more of the teachers' time that can be channeled towards teaching (Srinivasa et al., 2022). AI also involves the management of resources thereby optimizing their use and reducing wastage (Javaid, 2022). AI technologies that are incorporated in TVET programs allow students to develop an entrepreneurial mindset to create new products and services. It makes students ready for the dynamic job market due to Industry 4.0 (Onyango & Kelonye, 2022b). The incorporation of entrepreneurship within TVET curricula also builds upon the knowledge and skills of the students, provides them with practical skills, and nurtures innovation (Hong et al., 2023).

Research findings underscore AI's role in determining workforce skills and economic opportunities, particularly in developing nations such as Ghana, Nigeria, or Pakistan (Muogahlu and Ahmad, 2023; Muhammad et al., 2023). Applying AI in research and development helps to speed up the process of technological advancement and the overall development of economies (Besiroglu et al., 2022). Modern AI integrated TVET systems improve the employment rate and average wages of graduates by providing them with skills needed in Industry 4.0. These systems solve the skill deficit caused by AI and ML technologies by adopting competency-based education with AI-led enhancements in the curriculum and pedagogy (Onyango & Kelonye, 2022b). TVET system needs to further revamp its curricula, promote industry linkages, adopt new models of operation, secure financing, and develop teachers to prepare learners for future employment (Muhammad et al., 2023; Abdullah et al., 2022).

AI in education is economically advantageous in terms of cutting down on physical requirement and expenditures. AI tools such as ChatGPT are used for individualized and dynamic learning, assessment, and simulation that were earlier carried out using costly equipment (Stibbs et al., 2023; Somenko et al., 2023). Automated educational assessment enhances grading to facilitate institution resource management (Owan et al., 2023). AI-based predictive analytics enable course demand estimation and the allocation of resources necessary for increased educational performance improvement (Mara et al., 2023).

4.3 Addressing Workforce Skills Gap and Productivity

The incorporation of AI into TVET programs leads to an improvement in workforce capabilities, investors' draw, and economic diversification. Applying Artificial Intelligence in delivering TVET addresses the need for technical skills needed in the Fourth Industrial Revolution (Windelband, 2023). Integrating the current trends in science and technology including AI in TVET systems have strengthened the countries like Malaysia in producing quality human capital for the current labor market (Ye, 2023). This integration enhances graduate marketability, fosters industrial evolution, and makes people ready to address present epoch challenges (Adams & Cheah, 2022; Onyango & Kelonye, 2022).

AI technologies in TVET education foster long-lasting competencies such as interpersonal skills, problem solving, and resilience (Hutson & Ceballos, 2023). AI integration enables graduates to have the right technical skills required in the employment market upon their graduation and enhance policies by recommending improved learning mechanisms and lifelong learning (Kanbul et al., 2022). AR and VR also walk the students through real-like simulations, and this makes learning more practical (Hassan et al., 2021). This approach transforms the learning of TVET education to meet the workforce requirements while encouraging lifelong and life-wide learning.

4.4 Enhancing Workforce Productivity and Competitiveness

With the help of knowledge checkpoints and intelligent training systems, as well as with the help of adaptive technology in learning platforms, it is possible to give the learning process the personal aspect. This highlights that these systems can transform content and pace depending on the needs hence leading to improvement in knowledge acquisition and skill. Through the analysis of student performance, Muralidharan et al., (2019) spotted a positive correlation between adaptive instruction and increased productivity potential as risked by standardized tests. Moreover, using AI simulations or in a virtual environment, scenarios can be an actual experience in training where common safety hazards can be dealt safely. This helps learners get acquainted with those courses and work on them without the costs and dangers of mitigating their consequences in actual life situations. As a result, the workforce becomes ready and capable enough to meet the challenges of working in complexity and hence improves productivity (Radianti et al., 2020). Table 2 provided the information on cost saving using various methods that include the following:

Table 2 *Cost savings by AI empowerment*

| Research | Training Methods | Cost Savings |
|-------------------------|------------------------------|---|
| Kulik & Fletcher (2016) | Intelligent Tutoring Systems | Up to 30% compared to traditional classroom instruction |

| | | |
|--------------------------------|-----------------------------|---|
| Kaplan et al. (2020) | Virtual Reality Simulations | Up to 50% compared to physical training facilities |
| Arnich et al. (2021) | Adaptive Learning Platforms | 25-35% reduction in training costs |
| Becker et al. (2019) | AI-powered Simulations | 40-60% cost savings compared to real-world training |
| Gonzalez-Sanchez et al. (2022) | AI-enabled Online Courses | 20-30% lower costs than traditional classroom courses |

Although the research comes from various studies and focuses on different training approaches, the outcomes are consistent in showing considerable cost reductions over typical classroom instruction or on-the-job training facilities. There is a significant opportunity for cost reduction since the reported cost savings range from 20% to 60%. The results are particularly appropriate to current trends and practices because the timeline coincides with the training and education sectors' growing usage of AI and advanced technology.

4.5 Cost-effectiveness of AI-enabled Training

AI can significantly lower the costs associated with traditional training methods by automating specific processes and utilizing scalable technology solutions. Intelligent tutoring systems and adaptive learning platforms can present personalized instruction at a fraction of the cost of human tutors (Kulik & Fletcher, 2016). Moreover, AI-powered virtual simulations and AR tools can imitate real-world scenarios without the need for expensive physical equipment or facilities. This effectively reduces capital and operational expenditures (Kaplan et al., 2020). Student performance improvement due to the impact of AI is provided in Table 3.

Table 3 *Impact of AI on student performance*

| Research | AI-Enabled Learning Method | Improvement in Student Performance |
|----------------------------|------------------------------|---|
| Muralidharan et al. (2019) | Adaptive Instruction | 0.36 standard deviations in math and 0.22 standard deviations in Hindi. |
| Viberg et al. (2018) | Learning Analytics | Increased student engagement and better learning outcomes. |
| Chen et al. (2021) | Intelligent Tutoring Systems | 0.45 standard deviations improvement in test scores. |
| Jain et al. (2020) | Virtual Reality Simulations | 20-30% improvement in skill acquisition and retention. |
| Liu et al. (2023) | Adaptive Learning Platforms | 0.28 standard deviations improvement in overall academic performance. |

Each of the studies in the table describes positive effects on student performance that are identified as definite, from increased student involvement and overall academic achievement to increased test performance and skills. Such consistency suggests that utilizing AI teaching approaches may enhance learners' performance in various institutions offering education systematically. Most of the above research was probably conducted in specific educational settings or in a small way though they present promising results. These points suggest that additional large, longitudinal studies conducted in various learning contexts could be necessary for identifying the external validity and the delayed effects of these techniques based on artificial intelligence.

4.6 Bridging the Skills Gap and Addressing Labor Market Demands

AI-driven career guidance and job matching systems can facilitate the identification and to close the skills gap by examining labor market trends, job requirements, and individual competencies. They can suggest suitable training courses and opportunities to acquire more skills to enhance the human capital in the job market (Huang et al., 2020). In addition, learning analytics driven by artificial intelligence can help assess the effectiveness of teaching and learning, monitor students' performance, and determine how knowledge gaps can be addressed. This enrichment is the match between the skills obtained by TVET graduates and the requirements of employers in the labor market (Viberg et al., 2018) may help improve the match between TVET graduates and the available job offers. The effectiveness of the developed AI model in job matching is presented in table 4 below.

Table 4 *Efficacy of AI on job matching*

| Research | AI-Powered Job Matching System | Effectiveness |
|---------------------|---|--|
| Huang et al. (2020) | AI-assisted career guidance and job recommendation | Improved job-skill matching and job satisfaction |
| Cheng et al. (2019) | AI-driven job-skill matching platform | 35% increase in successful job placements |
| Singh et al. (2021) | Intelligent job recommendation system | 40% reduction in skills gap for technical roles |
| Lee et al. (2022) | AI-powered career counselling and job search | Higher employment rates and better job-fit |
| Zhou et al. (2023) | AI-enabled skills gap analysis and training recommendations | Increased workforce productivity by 15-20% |

Positive effects such as improved job match, improved job satisfaction, bigger employment probability, improved job fit, and higher productivity among the workers were observed by the studies. This means that due to the increased likelihood and effectiveness of such job placements, the AI assisted systems of job matching may prove beneficial to both the employers and the employee seekers. All the research that was conducted to show the usefulness of technology unveiled advantages, although, the extent of each varied in relation to environment and usage. Cheng et al. (2019) established that there is a 35% enhance of successful job placements while Zhou et al. (2023) observed a 15-20% surge in labor productivity. These variant stresses the fact that when assessing the potential consequences of implementing AI-supported job matching systems, the state of the organization and fine particulars of the implementation should be taken into account.

5. Successful Implementations of AI in TVET Institutions

The reviewed case studies reveal that the application of AI technologies have beneficial effects in Technical and Vocational Education and Training (TVET) institutions. TAFE Queensland being the largest supplier of vocational education in Australia, have incorporated virtual simulations and AI adaptive learning solutions in courses including nursing, construction and hospitality among others. The aforementioned technologies have tailored the development of performance competencies, knowledge acquisition, and attendees' interactions. Also, implementing these technologies, TAFE Queensland reveals that costs have been reduced, as well as the effectiveness of training has increased (TAFE Queensland, 2021). Nanyang Polytechnic in Singapore has adopted the use of artificial intelligence in counseling students academically and professionally through the use of AI chatbots and virtual assistants. The system identifies and recommends the courses and the career path that the student is most likely to embrace based on the students' interest, abilities and performance to foster students' success. From this approach, student retention as well as job placements have received a boost (Nanyang Polytechnic, 2020).

Lessons learned and scalability considerations:

- Infrastructure and resources = The technological infrastructure is required for the implementation of AI that includes a fast internet connection, processing power and storage devices at the TVET institutions. Zawacki-Richter et al. (2019) also mention funding and resources as important components of implementation and the extendibility of the initiative.
- Data privacy and ethics = Challenges such as opportuneness, privacy and ethics are taken up with the use of AI in education. To guarantee that student information is captured, processed, and archived in a way that meets all the legal requirements regarding data protection, TVET institutions must TVET (Holmes et al., 2021).
- Training and Support = It shows that instructors and faculty members need professional development and technical assistance as they seek to incorporate AI into instruction. Such abilities are necessary to integrate the AI tools into their teaching practice to the desired level (Popenici & Kerr, 2017).
- Ongoing assessment and development = They must also be assessed occasionally to identify areas of strength, weaknesses, and other potential gaps that the successful execution of AI-learning projects must address. For the purpose of expanding the learning process, feedback from the teachers, the industry partners, and students should be included (Zawacki-Richter, et al., 2019).

6. Challenges and Considerations

The integration of AI into TVET institutions in developing regions offers significant potential for enhancing the deployment of AI in learners and educators is a promising development which has a range of possibilities in TVET

institutions in developing regions of the world to enhance educational accomplishment and sustainable development. However, this integration comes with several problems such as technical or infrastructure barriers, ethical or social issues, and the lack of suitable policies. Solving these issues entails a complex and comprehensive Blending of resources that entails significant expenditure on technology, people, moral protection, rights of access, and flexibility in legal frameworks. Through these challenges, stakeholders can approach the deployment of AI technologies in ways that enhance the development of TVET institutions and ambitious socioeconomic goals.

6.1 Technical and Infrastructural Challenges

The TVET institutions in the developing region experience several technical problems, like the directors' low computer literacy, poor managerial know-how, and poor performance in the implementation of the performance monitoring system (Mohamad et al., 2023). Further, they face structural challenges such as lack of practice amenities, insufficient teachers, and crowded teacher-student ratio leading to low efficacy and qualitative learning (Otieno et al., 2022). These drawbacks inhibit the adoption of AI solutions that are prone to utilizing up-to-date computing centers and dependable Internet connection. Solving these problems requires additional investments in technological resources for improving computer literacy training, managerial capabilities, training amenities, faculty expansion, and decreasing class sizes among teachers (Subramaniam, 2022; Otieno et al., 2022). Upgrading computer laboratories and guaranteeing reliable connections to fast and high internet connections is also important (World Bank, 2021).

Based on the identified findings regarding the technical expertise barrier of educators and administrative staff to AI integration, TVET institutions need to push for improved managerial skills and industry linkages. To this end, directors are usually deficient in technical, human and conceptual competencies in order to facilitate collaborations within industries (Sohimia, et al., 2022). The provision of computer literacy, managerial knowledge and performance monitoring tools could help close this gap. Industry linkages can enhance collaborative learning, hence, the relevance and application of knowledge and skills offered by IVET and reformed TVET programs in accordance with industry needs and AI technologies (Onyango & Kelonye, 2022b). Such training partnerships with technology companies and universities can be a source of support and knowledge in these training initiatives (OECD, 2019).

6.2 Ethical and Social Considerations

Addressing the risks of implementing ethics and social norms in artificial intelligence in the context of education requires significant attention. AI demands a lot of personal data to be gathered and analyzed, which can create privacy and security issues. Implementation of effective data protection policies is required to protect against any incidences of leakage. Data can also be encrypted as well as many other sophisticated methods of protecting it from being stolen or accessed by unauthorized people. Minimizing risk on personal data requires the practice of compliance checks and audits, which can follow the General Data Protection Regulation (GDPR) (Hoofnagle et al., 2019).

Bias and fairness in AI algorithms form another category of concerns: AI systems have been known to reproduce or even magnify biases derived from data used to train these systems, a factor that may potentially cause unfair and LOCK discrimination in education. Incorporation of various genders, sexes, origin, culture, and ethnicity into training data also promotes equity as does implementing algorithms that detect & eradicate bias. Biased monitoring should be conducted routinely to ensure that the AI systems do not cause unfairness in decision making and to increase the accessibility of information on the AI decision making processes.

AI-based education technologies, when implemented, must be accessible to all across diverse learning settings to avoid increasing the education gap further. Given that all students for a class in question have access to requisite technologies in their learning then AI can bolster the learning outcomes. There are those who are disadvantaged and with little access will be left behind. AI technologies should also be developed to be accessible to everyone while agencies should put in place measures to ensure that clients with such disabilities get the devices and connectivity they require. There are scholarships, grants, and community support that can also help to make a step towards equalizing access to educational technologies (Anderson & Rainie, 2018).

6.3 Policy Development and Implementation

Thus, the formulation of the broad guidelines and legal standards is required to structure the substantiated and ethically balanced application of AI technologies in education. They remain limited or rudimentary in many geographical areas, and this leads to variations and potential exploitation (Nguyen, et al., 2023). Schools should ensure that they have clear guidelines on how to use AI, and the factors to consider when conducting ethical use of the procedure. The need to balance the opportunities for creating innovation against the risks of regulation is acknowledged. Without much regulation it becomes challenging for the advancement of technologies and with much regulation the advancement of good technologies is hindered, and the ethical and social concerns are not

handled as comprehensively. Consequently, the set of prescripts points to the fact that regulatory systems should be as flexible as possible and allow for innovation at the same time but should unambiguously define norms of data protection, non-discrimination, and reasonable treatment.

Others are policy enforcement and compliance audits, which are even more challenging in the decentralized system of education. Hence, there is a need to enhance the monitoring processes and ensure compliance with the set-up plans to enhance the effectiveness of the policies. The mere page turning and the changes in policy where necessary can only be done bearing in mind the technological factors as well as the feedback of the affected or interested party. It is also paramount to include educators and policymakers, professionals, businessmen, and other stakeholders in the formulation of policies so that everyone ensures that the formulated regulations are reasonable and comprehensive (Miao et al., 2021).

By addressing these concerns, stakeholders can ensure that the implementation of AI in TVET enhances education and provides efficient solutions to address the following issues are highlighted below as some that can be addressed through the use of artificial intelligence to support and enhance the outcomes of TVET systems and to play a positive role in the social and economic progress of nations.

7. Future Directions and Opportunities

In the rapidly transforming field of education, AI and similar technologies continue to manifest as potential enablers for Technical and Vocational Education and Training (TVET). With the incorporation of adaptive learning systems, VR/AR environments, blockchain, and AI-enhanced collaborative platforms, this innovation bear potential to remarkably transform the teaching practices, curriculum designing, and assessment processes. As this review shows, the application of AI has the potential to revolutionize learning by providing personalized solutions for learner and skill training and to close achievement gap to improve learning outcomes in line with the modern world demand for skilled jobbers; this requires collaborative endeavors of educators, policymakers and industrial partners to spearhead the application of AI innovations in learning.

7.1 Adaptive Learning and Immersive Technologies

Some examples include adaptive learning systems that employ AI to recommend the best pedagogy and content depending on the student's learning progression and mannerisms as a way of improving learning (Rane et al., 2023). The features of these platforms include the ability to change the levels of difficulty and offer specific content that is teachable for the learner's benefit.

Some of the advantages include the fact that with the use of advanced AI- integrated VR/AR systems, students can practice in realistic environments as they train, thereby improving their performance without the risks of injury (Aladag et al., 2022). In addition to protracting by AI, these systems assist persons with physical impairment and enhance the interface between human and computer (Nagy et al., 2023). The inclusion of AI in horning Metaverse Realistic Content in the educational environment is that of creating personalized learning paths, real-time feedback, and through realistic scenes (Nagy et al., 2023). When incorporating AI in VR training, the results have shown when implementing AI-assisted VR training, it can provide effective evidence-based training with little to no intervention from the instructor on the side; further, it has enhanced communication and feedback (Lee & Youm, 2022).

Educational applications of VR and AR technologies are changing the way people learn trades in medicine, engineering, construction and rehab. Some of the advantages of using VR are improved learning and knowledge retention because it provides the actual scenario and improved engagement because students are more motivated to learn (Ravichandran & Mahapatra, 2023). AR and VR support procedural learning and operational skills in vocational training, creating interactive and immersive learning environments that aid in intercultural communication and cognitive development (Ali et al., 2023).

7.2 AI in Student Support and Skill Assessment

AI in TVET enhances student outcomes through predictive analytics, offering personalized support to at-risk students by analyzing learning behaviors and performance in real-time (Kero & Olana, 2023). AI-driven skill assessment tools, like the Video Semantic Aggregation (ViSA) framework, improve skill assessment by discovering and aggregating semantic parts across spatiotemporal dimensions (Onyango & Kelonye, 2022). In minimally invasive surgery, AI aids in surgical tool segmentation and skill assessment, utilizing deep neural networks to automate technical skill evaluation (Li et al., 2022; Papp et al., 2022).

7.3 Blockchain and Collaborative Learning Platforms

Blockchain technology secures and verifies credentials and achievements in TVET programs. It ensures the immutability and transparency of academic credentials (Ambast & Sumesh, 2022) and enhances online security

for virtual reality applications in education (Shahrin et al., 2021). Smart contracts create tamper-proof data storage, ensuring certificate authenticity (Shakila & Rama, 2023).

AI-enhanced collaborative learning platforms facilitate peer-to-peer learning and global connectivity with experts and mentors, leveraging AI tools to personalize instruction and provide feedback (Roschelle, 2021). Platforms like EIDU optimize content for individual learners through personalization algorithms and autonomous assessment tools, fostering continuous improvement and collaboration among content providers and researchers (Skulimowski, 2022). AI-based solutions, like those proposed for cyber-Peer-Led Team Learning (cPLTL), enhance learning experiences by providing automated feedback to instructors (Friedberg, 2022).

To maximize AI benefits in TVET, stakeholders should focus on continuous professional development for educators, AI literacy curriculum development, and resource allocation for AI implementation. Training programs can enhance educators' competencies in AI technologies (Onyango et al., 2022), while multi-stakeholder collaborations ensure access to digital resources and infrastructure (George et al., 2023). Policymakers should develop comprehensive policies that address pedagogical, governance, and operational aspects of AI integration, ensuring privacy, security, and accountability (Chan, 2023).

Multi-stakeholder collaboration frameworks, like the Quadruple Helix Innovation Model, incentivize institutions and industry partners to innovate and collaborate on AI-driven TVET programs (Lin et al., 2022). Incentive mechanisms based on game models can address challenges in collaborative intelligence settings, encouraging optimal participation and long-term interactions among stakeholders (Legg-Jack & Ndebele, 2022). Sustainable digital business models promote public-private partnerships, ensuring inclusive access to AI technologies and preventing the digital divide (Capasso & Umbrello, 2023).

7.4 Strategic Collaboration and Policy Development

Industry stakeholders ensure the relevance of TVET programs through public-private partnerships, providing real-world insights and aligning curricula with market demands (Legg-Jack & Ndebele, 2022). These partnerships enhance practical skills training and promote knowledge exchange between sectors (Ibrahim & Nashir, 2022), improving the employability of graduates (Otieno et al., 2022).

Workforce development initiatives using AI can upskill and reskill employees, addressing technological advancements and bridging skills gaps (Sofia et al., 2023). Projects like SkillSync™ align skills needs with learning outcomes and training, enhancing workforce agility and preparedness (Robson et al., 2022). AI integration in research software development equips employees with necessary competencies for the evolving technological landscape (Jaiswal et al., 2022).

Investing in research and development is crucial for continuous improvement in AI technologies for education (Bhimdiwala et al., 2022; Liu & Baucham, 2023). Collaboration between academic institutions and tech companies accelerates advancements in AI, leading to more effective educational tools and systems (Tan, 2023; Latif et al., 2023). These partnerships enhance teaching quality, align education with societal needs, and ensure engaging and effective learning environments (Evans & Miklosik, 2023).

AI technologies can significantly enhance TVET by improving teaching methods, curriculum development, and student assessment (Onyango & Kelonye, 2022). Key trends and collaborations among educators, policymakers, and industry stakeholders should focus on integrating ICT effectively, addressing challenges like limited financing and inadequate IT infrastructure (Pavlova, 2020), and adapting to the changing landscape of Industry 4.0 to 5.0 (Hassan et al., 2021). A systematic approach to incorporating AI-driven interventions in TVET curricula is needed to equip graduates with skills demanded by the evolving labor market (Legg-Jack & Ndebele, 2022). By fostering partnerships and embracing AI technologies, stakeholders can collectively enhance TVET programs to meet the demands of the modern workforce.

8. Results and Discussion

The integration of AI in TVET programs offers significant economic benefits by enhancing workforce competitiveness, driving economic growth, and improving cost-effectiveness and efficiency. AI-powered platforms deliver personalized learning experiences by tailoring educational content to individual needs, thus accelerating skill acquisition and improving outcomes.

Economic Benefits:

- **Workforce Competitiveness** = AI technologies ensure that TVET programs align with job market demands by analyzing labor market trends and forecasting the demand for specific skills.
- **Cost-Effectiveness** = AI tools reduce physical resource needs and operational costs by replacing expensive equipment and streamlining administrative processes.

Innovation and Entrepreneurship = AI boosts productivity and fosters innovation by automating administrative tasks, optimizing resource management, and inspiring entrepreneurial thinking among students.

Empirical evidence highlights AI's role in shaping workforce skills and economic mobility, especially in developing countries.

Addressing Workforce Skills Gap = Integrating AI into TVET programs enhances workforce skills, attracts investments, and promotes economic resilience. AI-driven interventions help meet the demand for technical skills required in the Fourth Industrial Revolution by focusing on competency-based training and updating TVET curricula.

Clinical Implications = To support the data clinically, reliable sources were referenced, such as empirical studies highlighting AI's impact on job market readiness and economic growth. For instance, studies by Maghsudi et al. (2021) and Liu et al. (2023) provide evidence on AI's effectiveness in personalized learning and skill development, reinforcing the findings of this review.

9. Conclusion

The article emphasizes, in short, how artificial intelligence (AI) is having a big impact on technical and vocational education and training (TVET). To improve learning outcomes, close the skills gap in the workforce, and improve TVET systems, it highlights AI as a critical driver. AI technology integration provides adaptive evaluations, efficient skill development, and personalized learning experiences. Individualized learning needs assessments and the provision of focused support to students are made possible by artificial intelligence. To fully realize the advantages of AI in TVET, however, strategic partnerships between academic institutions, business associates, and legislators are needed. These collaborations ensure that TVET programs remain relevant in a rapidly changing digital context while also encouraging innovation and facilitating the sharing of knowledge. To create an environment that is conducive to the use and integration of AI technology in TVET, policy support is essential.

Additionally, for TVET educators to improve their pedagogical abilities and digital literacy and effectively use AI tools, they must engage in ongoing professional development. Teachers should graduate from training programs with the skills and knowledge necessary to use AI in the classroom. Additionally stressed are ethical issues such as data protection, responsibility, and openness that are related to the use of AI in education. In general, the article promotes a thorough strategy for integrating AI into TVET that considers advances in technology, creative teaching methods, and stakeholder involvement. TVET institutions can better prepare students for the skills of the Fourth Industrial Revolution, meet the needs of the economy, and meet the needs of society by utilizing AI's potential. The ability of AI to completely change teaching and learning methods, improve workforce preparedness, and influence how education is shaped in the digital era is what makes it so transformative in TVET.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design:** Muhammad Irsyad Abdullah; **data collection:** Asif Iqbal Hajamydeen; **analysis and interpretation of results:** Muhammad Irsyad Abdullah, Asif Iqbal Hajamydeen, Md Gapar Md Johar; **draft manuscript preparation:** Muhammad Irsyad Abdullah, Asif Iqbal Hajamydeen. All authors reviewed the results and approved the final version of the manuscript.*

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