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Augmented Reality in Vocational Education : Trend, Acquired Skills, and Future Work

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Abstract: This study aims to explore the role of Augmented Reality (AR) in enhancing practical skills within vocational education, particularly in response to the evolving needs of the educational sector. Through a bibliometric analysis and comprehensive literature review, this research examines trends in AR research from 2003 to 2023. The study focuses on publication growth, citation impact, research focus, and subject area. The research method used includes bibliometric analysis and systematic literature review, with data visualized through tools like VOSviewer and Tableau. Data were collected from various academic databases, examining the distribution of publications, research impact, and citation patterns over the years. Data were analyzed using quantitative and cluster analysis to categorize research trends into six clusters: industrial architecture, biomedical surgery, product development, learning methods, AR's positive impact, and acquired skills. The study results showed that AR has a positive impact on several skill sets but may occasionally hinder others. The research also reveals that while AR applications are gaining momentum, certain areas such as Agricultural and Biological Sciences, Economics, and Nursing remain largely unexplored. This review highlights the importance of advancing AR in untouched fields and emphasizes the need for further investigation into the systematic assessment of skills acquired through AR, making this study vital for educational technology, vocational instructors, and institutions aiming to implement AR technologies effectively.

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Introduction

In the evolving landscape of education, the pressing need to upgrade vocational skills intersects with the transformative potential of Augmented Reality (AR). As industries advance, so do the requisite skills, prompting a reevaluation of vocational education's role in equipping individuals with relevant competencies (Billett, 2020). AR emerges as a pivotal ally in this pursuit, offering a dynamic platform to enhance vocational learning. The integration of AR addresses the imperative to upgrade vocational education by providing an immersive and interactive learning environment (Aprea & Cattaneo, 2019). Beyond traditional pedagogies, AR facilitates practical skill acquisition, fostering a bridge between theoretical knowledge and real-world application (Nassar et al., 2021).

As industries increasingly embrace technological advancements, industry acceptance relies heavily on the possession of relevant and up-to-date skills (Lewis, 2020). This section will explore the skills that are highly valued by industries, emphasizing the gap between traditional educational approaches and the dynamic demands of the professional landscape.

Identifying these skills serves as a precursor to understanding how AR can be leveraged to address this disparity and equip vocational students with a competitive edge in the job market. The role of AR in vocational education becomes pivotal, offering a dynamic means to align skill development with the demands of contemporary workplaces (Sharma et al., 2022).Current vocational education programs, however, often lag behind in terms of adapting to these changes. Traditional pedagogical methods, while foundational, may not fully equip students with the hands-on, technical skills needed in today's dynamic job market (Uduafemhe et al., 2023). This creates a pressing need for innovative educational tools that can bridge the gap between conventional learning methods and the practical skills required by industries.

AR has the potential to address this need by offering an immersive and interactive learning environment that enhances skill acquisition, particularly in fields where traditional training may fall short (Wang, 2020). By simulating real-world scenarios and allowing for experiential learning, AR can help vocational students gain the up-to-date, practical skills that industries demand (Boettcher et al., 2023). This research is therefore crucial in exploring how AR can be integrated into vocational education to ensure that students are equipped with the competencies necessary for the future workforce. Furthermore, this study's focus on previously untouched areas within AR research provides a more holistic approach, making it even more relevant in today's rapidly changing educational and professional landscape.

Prior study has examined the use of AR in vocational education. Chiang et al. (2022) review on various aplication of AR in vocational training. Thus, the mapping conducted by this study exclusively focuses on rapidly emerging regions. Another work has been done by Supriyanto et al (2023) reveal the vocational learning experiences gained from using AR. However, there is currently a lack of solid information about the specific empirical effects of AR on users' skill acquisition. Therefore, it only reveals what has been researched and does not provide recommendations for other areas that have not been researched.

This study aims to bridge the research gap on AR in vocational education, an area that has not been widely explored, by providing insights through bibliometric analysis and systematic literature review. It will focus on the utilization of AR in underrepresented subject areas and highlight less-explored skills acquired through AR. The findings will benefit researchers in educational technology, vocational educators, and educational institutions by guiding the advancement of AR in these domains. Additionally, the insights will support educational policymakers in developing evidence-based recommendations for implementing AR-driven curricula and strategies, fostering a more innovative educational system aligned with industry needs. The research objectives include analyzing the quantitative distribution of AR publication in vocational education (RO1), revealing citation patterns (RO2), mapping research focuses (RO3), identifying skills gained from AR use (RO4), and reflecting on future AR development in vocational education (RO5).

Research Method

This study employs a fusion of bibliometric analysis (BA) and systematic literature review (SLR) metods. BA is employed to examine the trend, research focus, and patterns of study subjects pertaining to AR in vocational education. While SLR is utilized to explore the skills acquired in the use of AR and the diverse tools employed in the development of AR in vocational settings. The research process consists of three phases (Figure 1). BA is a technique used to detect and organize scientific patterns and research (Vílchez-Román & Mauricio-Salas, 2021). The data source for this research was only obtained from the Scopus

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database. Scopus offers a broader and more prestigious scope of coverage compared to both Web of Science and PubMed (Yeung, 2019).

In Phase 1, the search criteria are defined to identify records in the Scopus database. Data retrieved from 2003 to 2023 with the total records of 5,167 documents The retrieved records are filtered during the data filtering phase. In Phase 2, documents are filtered based on specific criteria: they must be articles in English, related to AR and vocational education, and not duplicates. After applying these criteria, 1,096 documents were selected for further research. In Phase 3, the documents were exported to VOSviewer and Tableau Desktop for bibliometric analysis, focusing on publication trends and citations. A systematic review was conducted, extracting key data on acquired skills and AR tools in vocational education. Finally, thematic analysis identified main research themes, with findings synthesized to provide insights for future studies.

Results and Discussion

Publication Trend

Quantitative Distributions of Publications

The research trend in AR in vocational education is steadily growing annually (Figure 2). This surge demonstrates the advancement and growth of AR technology in vocational education. The rise in publications is congruent with the progress in digital technologies across several domains along the year.

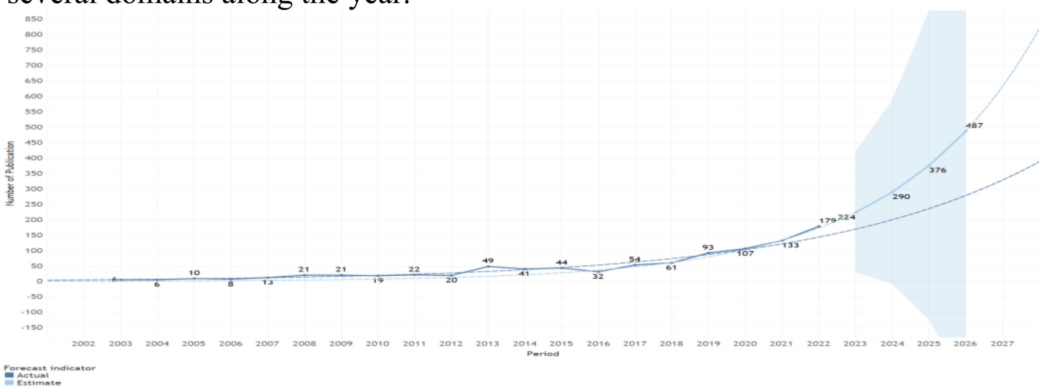

Figure 1. Publication Distribution Annualy and Forcasting

Figure 1 shows trends, research on AR in vocational education is projected to continue its upward trajectory over the next two years, with a high confidence level of 95%. This indicates a growing interest and recognition of AR's potential benefits for vocational education. As technology advances, educators and researchers are expected to explore innovative ways to integrate AR into vocational training programs, enhancing the learning experience and better preparing students for real-world challenges.

AR can replace or supplement traditional technologies to transform vocational learning and industry. Remote support lets specialists deliver real-time guidance without the requirement for physical presence or fees (Moourtzis et al., 2020). AR-based training simulations replace pricey equipment and provide realistic, cost-effective hands-on skill development. AR aids industrial equipment maintenance, repair, and inspection, reducing downtime and increasing efficiency (Sattarpanah et al., 2022). AR simulations of dangerous scenarios in controlled surroundings can improve safety training (Li et al., 2018). AR also simplifies assembly, reduces tool use, improves design visualization, and customizes learning (Moutzis et al., 2019). Using AR, organisations can improve resource utilisation, training efficiency, and cost savings while changing vocational education and industry (Jetter et al., 2018).

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This rising trend can be driven by educational institutions, industry stakeholders, and government authorities, all aiming to improve workforce competencies in alignment with technological progress (Oviawe et al., 2017). AR superimposes digital content, such as images, videos, or 3D models, onto the physical environment, creating an engaging and immersive experience. In vocational education, this technology can be utilized in training programs, workshops, and skill-enhancement activities. Collaborations between technology developers, educators, and industry professionals are essential for promoting AR adoption in vocational training and ensuring it meets industry needs.

Prevailing Patterns of Citation

Publications are grouped according to year of publication and then analyzed for total citations and average citations per publication (Figure 2). The citation pattern also shows a different pattern from the total publication trend. Publications tend to increase each year while the number of citations decreases.

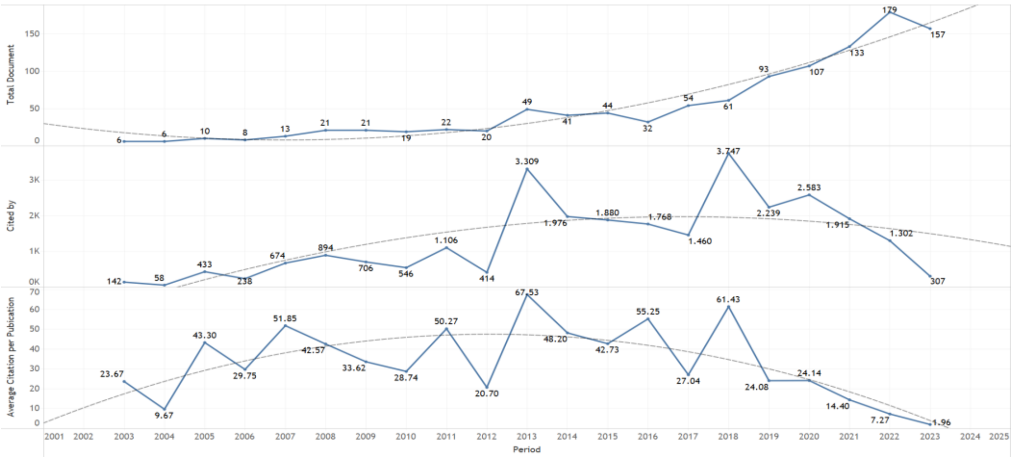

Figure 2. Citation Analysis

The observed phenomenon of increasing publications in AR research within vocational education, coupled with a decrease in the number of citations and average citations per publication, may be attributed to several factors. One possible explanation is that as the field gains popularity, there might be a surge in the quantity of research outputs, but not all of them may necessarily contribute ground breaking or widely influential insights. Additionally, the novelty of AR in vocational education could lead to a rapid generation of diverse studies, ranging from exploratory to more specialized topics (Akçayır & Akçayır, 2017). This diversity may dilute the citation impact across a larger pool of publications, resulting in a lower average citation per publication.

Furthermore, the nature of emerging technologies, such as AR, often involves incremental progress and iterative research. Initial studies may lay the groundwork for subsequent work, and citations may spread across various papers within a broader research domain rather than concentrating on a few seminal publications. This diffusion of citations can contribute to a increase in both the number of citations and the average citation per publication. In summary, the observed trend could reflect the evolving and exploratory nature of AR research in vocational education, where a surge in publications does not necessarily translate to a proportional increase in citation impact due to factors like diverse research focus, incremental progress, and a growing but dispersed body of knowledge.

Research Focus

Research trends in AR in vocational education are analyzed by examining each document and extracting the primary keywords, including both author keywords and publisher keywords. This study is crucial for comprehending patterns in the development of

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themes and identifying focal points that hold the potential to be subjects for subsequent investigation, progress, and discovery. The data were analyzed using VOSviewer, employing the complete counting co-occurrence of all term's method. There are a total of 7932 keywords. The minimum number of times a keyword must occur is 5, and out of these, 466 keywords fulfill this criterion. Figure 3 displays the network representation of the keyword.

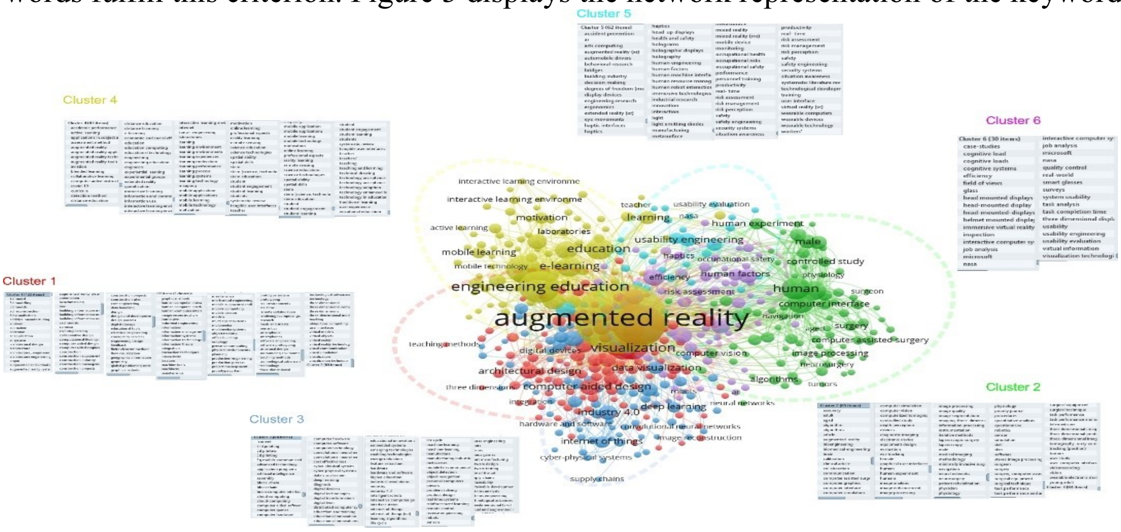

Figure 3. Keyword Network Visualization

Figure 3 shows the emergence of keywords and their relationships. The size of each circle indicates the frequency of keyword occurrence in the collected documents. The analysis is divided into six keyword clusters, each representing an interconnected theme.

Cluster 1 consists of 122 keywords, with dominant ones including *virtual reality*, *visual*, *construction industry*, *architectural design*, and *computer-aided design* (CAD). The link between *AR* and this cluster lies in the integration of AR and *virtual reality* (VR) with CAD, revolutionizing the construction and architectural design industries. This technology allows professionals to create immersive, interactive experiences by integrating CAD elements into virtual environments or embedding them in the physical world through AR. It enables real-time simulation of construction projects, enhancing design evaluation, problem detection, and decision-making before physical construction begins (Banfi, 2021; Solanki et al., 2023). AR and VR, coupled with CAD, provide powerful tools for modeling, visualization, and collaboration, driving innovation in project planning and execution (Kolaei et al., 2022).

Cluster 2 contains 85 keywords, with *human*, *article*, *procedures*, *biomedical engineering*, *surgeon*, and *neosurgery* being the most frequent. The integration of AR with biomedical engineering and surgery marks a significant leap in healthcare. AR enhances precision in surgical procedures by offering real-time visualizations during operations, improving the surgeon's decision-making and efficiency (Al-Gailani et al., 2021). By integrating patient data with visual displays, AR improves the accuracy of procedures and overall patient outcomes. It creates a more sophisticated surgical environment, connecting real-time data with innovative technology (Cofano et al., 2021).

Cluster 3 includes 84 keywords such as *artificial intelligence* (AI), *internet of things* (IoT), *data visualization*, *product design*, and *manufacturing*. The convergence of AR with AI, IoT, and data visualization provides new avenues for smarter product design and manufacturing. AI and IoT empower AR to deliver real-time interactive visual experiences, while data visualization simplifies complex information, accelerating product design processes (Devagiri et al., 2022). In manufacturing, AR supports worker training, production efficiency, and machine monitoring, fostering innovation in the industry (Olshannikova et al., 2015).

Cluster 4 consists of 83 keywords, dominated by *engineering education*, *students*, *e-learning*, *motivation*, *engineering*, and *vocational education*. AR is reshaping engineering and vocational education by making learning more interactive and immersive. It helps students visualize engineering concepts, making them easier to understand and relate to practical applications (Takrouri et al., 2022). Through AR-based e-learning, students gain access to more flexible, independent learning environments, increasing their motivation and engagement. AR also prepares students for real-world challenges through simulations and virtual practicums that build practical skills (Lester & Hofmann, 2020).

Cluster 5 contains 62 keywords, with *situation awareness*, *personnel training*, *safety engineering*, *decision making*, *accident prevention*, and *human engineering* being the most prominent. AR enhances situational awareness by providing real-time data and visual support, improving decision-making and operational safety (Woodward & Ruiz, 2022). It offers interactive training simulations that build personnel readiness for critical situations, while in safety engineering, AR helps identify risks and offer preventive solutions (Alirezaei et al., 2022). By integrating AR into decision-making processes, organizations can achieve more informed, efficient analysis (Martins et al., 2022).

Cluster 6 includes 30 keywords, such as *efficiency*, *inspection*, *task completion time*, *task analysis*, *job analysis*, and *usability engineering*. AR improves operational efficiency by delivering task-specific information directly to workers, minimizing distractions and speeding up task completion (Marino et al., 2021). In inspection processes, AR enhances task analysis through real-time visualization and guidance, reducing errors and improving accuracy. It also shortens task completion time by providing visual support during tasks. Task and job analysis benefit from AR by offering better visibility and comprehension of work complexities, contributing to more effective performance. In usability engineering, AR ensures intuitive interfaces, improving user engagement and productivity (Lee, 2020; Sirakaya & Kilic, 2018).

The clustering results show that the use of AR has a positive impact in various clusters, ranging from construction and architectural design, biomedical surgery, smart manufacturing, engineering education, engineering, to operational efficiency analysis (Table 1). The analysis revealing the distribution of documents across subject areas in AR research within vocational education highlights a significant trend of concentration in specific disciplines while identifying notable gaps in others. An analysis of the number of documents was carried out based on subject area. One document may have more than one subject area.

Table 1. Documents by Subject Area

Subject Area	Documents	Percentage
Engineering	604	27,33%
Computer Science	585	26,47%
Social Sciences	275	12,44%
Mathematics	93	4,21%
Physics and Astronomy	90	4,07%
Materials Science	84	3,80%
Medicine	57	2,58%
Business, Management and Accounting	52	2,35%
Chemical Engineering	45	2,04%
Psychology	44	1,99%
Environmental Science	37	1,67%
Arts and Humanities	35	1,58%
Earth and Planetary Sciences	29	1,31%
Biochemistry, Genetics and Molecular Biology	28	1,27%
Decision Sciences	28	1,27%

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Subject Area	Documents	Percentage
Energy	28	1,27%
Chemistry	27	1,22%
Health Professions	27	1,22%
Neuroscience	14	0,63%
Multidisciplinary	11	0,50%
Agricultural and Biological Sciences	5	0,23%
Economics, Econometrics and Finance	3	0,14%
Immunology and Microbiology	3	0,14%
Nursing	3	0,14%
Pharmacology, Toxicology and Pharmaceutics	2	0,09%
Dentistry	1	0,05%

Documents in engineering, computer science, and social sciences show that these fields are leading the way in incorporating Augmented Reality (AR) into vocational education, benefiting from AR's technological and interactive features to foster innovation and research. However, the lower representation of documents in Agricultural and Biological Sciences, Economics, Econometrics and Finance, Immunology and Microbiology, Nursing, Pharmacology, Toxicology and Pharmaceutics, and Dentistry suggests future research. This lack of focus may be due to the nature of vocational education in these fields or perceived AR integration issues (Wu et al., 2013). Addressing these gaps could increase academics' and practitioners' awareness of AR's numerous occupational uses and benefits, allowing them to innovate and improve learning experiences through strategic integration. The distribution of materials across academic areas implies a need for a more comprehensive and interdisciplinary approach to AR research in vocational education to understand its function in improving diverse disciplines.

Acquired Skills

AR holds significant promise in the field of vocational education, particularly in the development of practical skills and the assessment of various soft skills. This article presents an analysis of the skills that were assessed, together with the outcomes of their efficacy, and the technology employed to accomplish these assessments. This article curates 35 empirical research that includes the research topic, utilized methodologies, acquired skills, and the relevance of the value enhancement.

Table 2. Empirical Evidence Towards Acquired Skills

Author	Respondent	Field Area	Tools	Acquired Skills	Effect
Akçayır et al., 2016	76 first-year university students	Physic	AR Tech	laboratory skills	/
Martín-Gutiérrez et al., 2010	24 mechanical engineering freshman	Mechanical Engineering	AR-Dehaes	spatial ability	/
Carbonell & Bermejo, 2017	73 engineering students	Geography	AR DTM	relief interpretation skill	/
Deshpande & Kim, 2018	14 workers	Furnitures	AR RTA	spatial problem-solving abilities	/
Abhari et al., 2014	Junior residents	Medical	Mixed Reality	nonclinicians performance speed performance	/ /
Singh et al., 2019	60 first-year electrical students	Electrical Engineering	ARLE	laboratory skills	/
Kwiatek et al., 2019	21 professional pipe fitters & 40 engineering students	Consctruction	scan-vs-BIM	spatial cognition	/
Sirakaya & Kilic, 2018	46 computer hardware students	Electrical Engineering	HardwareAR	self-efficacy assembly skills speed performance	- / /
Faridi et al., 2021	80 engineering students	Physics	AR-based learning	critical thinking	/

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Author	Respondent	Field Area	Tools	Acquired Skills	Effect
Gargrish et al., 2021	80 polytechnic students	Mathematic	AR-based GLA	memory retention abilities	/
Borgen et al., 2021	36 aeronautical engineering students	Aviation	AR flight deck	knowledge retention speed performance	/ /
Vassingh et al., 2020	3 architectur engineering construction class	Architecture	Skope	collaborative learning	/
Lee, 2020	40 freshman carpentry class	Furniture	3D AR	furniture carpentry skills mortise–tenon joint	/ /
Hussain et al., 2012	elder drivers & young drivers	Transportation	ARV & OARsim	elder's driving ability youngster driving ability	\ /
Srinivasa et al., 2021	118 engineering laboratory students	Mechanical Engineering	AR & VR	self-efficacy	/
Carbonell-Carrera, & Hess-Medler, 2019	73 engineering students	Geography	SDI LiDAR	geospatial thinking	/
Farshad et al., 2021	2 experienced spine surgeons and 2 biomedical engineers	Medical	fluoroscopy-free AR	pedicle perforation surgery accuracy speed performance	- / /
Urbano et al., 2020	440 mechanical engineering students	Mechanical Engineering	AR DC circuit puzzle	self-regulation skills analyze electric circuits spatial ability	/ / /
Kumar et al., 2022	78 engineering students	Electrical Engineering	ARITE	collaborative skills system concepts	- /
Tuli et al., 2022	107 first-year engineering students	Mechanical Engineering	AR-based lab manual	spatial abilities technical skills problem-solving abilities	/ / /
Omar et al., 2019	30 engineering students	Mechanical Engineering	AREDApps	orthographic engineering drawing	/ /
Weng et al., 2023	197 students from three vocational high schools	Civil Engineering	AR 3DApps	spatial abilities digital skills	/ /
Cevahir et al., 2022	94 vocational students	Programming	ARAWEs	problem solving skills	/
Han et al., 2022	104 junior vocational students	Automotive Engineering	AR-based assembly instruction	assembly quality speed performance	/ /
Rowen et al., 2019	211 operators	Marine Transportation	WARDs	situation awareness self-efficacy trust workload	/ / / /
Verner et al., 2022	99 first-year industrial engineering stydents	Industrial Engineering	Vuforia Studio	integrative thinking skills	/
Rohidatun et al., 2017	Technicians	Engineering	ARVR	assembly quality speed performance	/ /
Dutta et al., 2023	128 engineering studens	Electrical Engineering	Unity 3D and Vuforia SDK	solve complex Boolean equations critical thinking skills	/ /
Al-Gailani, 2021	Internally test	Medical	Intelligence box-trainer LabVIEW	laparoscopic surgery	/
Teguh Martono et al., 2022	Internally test	Military	AR Shooting Simulator	distance estimation shooting accuracy	/ /
Tan et al., 2022	15 adults' disabilities work theraphy	Psychiatric Rehabilitation	REAP program	cognitive skills	/

Note: (\) Decrease; (/) Increase; (-) No effect/ No differences

The integration of AR in vocational education has demonstrated varied effects on the acquisition of skills across a spectrum of disciplines. The introduction of AR into vocational education has yielded a diverse array of outcomes regarding the acquisition of skills. A meticulous analysis of the data indicates a multifaceted impact on a broad spectrum of abilities, both in terms of increased effectiveness and, interestingly, occasional decreases in certain skills. Several skills, such as laboratory skills, spatial abilities, assembly skills, critical thinking, memory retention abilities, knowledge retention, collaborative learning, furniture carpentry skills, and many others, consistently show an increase in effectiveness. This positive trend suggests that AR significantly contributes to the improvement of these skills in vocational education.

However, there are instances of a decrease in certain skills, such as elder's driving ability and engineering drawing skills. The decrease in elder's driving ability may be attributed to the potential challenges faced by older individuals in adapting to AR-driven environments (Derby & Chaparro, 2020). On the other hand, the decrease in engineering drawing skills could be due to factors such as overreliance on digital tools, which may impact traditional drafting abilities (Yang et al., 2023). It's essential to note that the variable impact on self-efficacy and collaborative skills, with some cases showing no effect, indicates that the influence of AR on these aspects is context dependent. The effectiveness of AR in vocational education is contingent on factors such as the nature of the skill, the learning environment, and individual differences among learners. An important obstacle is the potential discrepancy between AR applications and conventional learning methods. Transitioning from traditional teaching methods to AR-based approaches necessitates a meticulous reassessment of pedagogical strategies (Hanid et al., 2020), compelling educators to modify instructional approaches to seamlessly include AR into the curriculum. Hence, this study emphasizes the necessity of implementing a suitable learning model framework to effectively utilize AR in vocational education.

Reflection and Future Work

The findings underscore the transformative potential of AR in vocational education, highlighting its promising benefits for future learning and skill development. The rise in publications reflects a growing interest in digital technologies across various fields, with collaborative efforts among educational institutions, industry stakeholders, and government authorities being crucial to enhancing workforce competencies and keeping pace with technological advancements. The continued upward trajectory in AR research within vocational education suggests a sustained commitment to harnessing AR's potential, as indicated by the increasing citation impact of diverse research efforts.

However, several areas remain unexplored, particularly in Agricultural and Biological Sciences, Economics, Nursing, Pharmacology, and Dentistry, presenting opportunities for further investigation. Researchers can contribute to a more comprehensive understanding of AR's role in advancing vocational education across a broader range of disciplines. The transition from traditional teaching methods to AR-based approaches necessitates a reassessment of pedagogical strategies, underscoring the need for a conceptual framework to integrate AR effectively into vocational learning. A meticulous analysis of data on AR integration reveals a nuanced impact on various skills, raising critical questions about the contextual factors influencing AR's effectiveness.

Future research should thoroughly examine AR's impact on industry-specific competencies, particularly those related to sustainability, and collaborate closely with industries to identify the competencies sought in various sectors. This targeted approach ensures that AR interventions effectively address skill gaps within specific professions. Assessing the effectiveness of skills acquired through AR applications requires sophisticated methodologies. A meta-analysis approach can provide a comprehensive evaluation of AR's overall impact, enabling a quantitative understanding of its influence on skill development and aiding in synthesizing diverse research findings. Future work should adopt a reflective stance, exploring the dual nature of AR's impact on skills, especially those related to employability and sustainability.

Conclusion

The benefits of AR in vocational education are clear, as shown by the increasing number of publications and the growing acceptance of AR applications across various disciplines. Analysis of publication trends suggests a sustained rise in AR research within vocational education, with a proportional increase in citation impact. Research clusters include construction and design, biomedical surgery, product development, learning methods, and acquired skills, highlighting AR's broad influence. However, certain fields remain underrepresented, indicating untapped potential. The varied impact of AR on skill acquisition—showing positive trends in some areas and declines in others—highlights the need for nuanced assessments.

Recommendation

Advancing research on AR in vocational education requires developing comprehensive pedagogical frameworks that align AR integration with educational objectives and industry standards. Collaborating with industry stakeholders will deepen the understanding of the specific skills needed for the evolving workforce. It is essential to address barriers such as the high cost of AR technologies, inadequate infrastructure, and resistance from educators. Additionally, research should focus on the long-term effectiveness of AR in skill retention and employability, employing meta-analytical approaches to quantify its impact. Education policymakers need to create supportive policies and funding initiatives that prioritize AR in vocational education, ensuring equitable access to technology and resources for all institutions.

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