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

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Abstract: Augmented Reality (AR) can improve practical skills, which are needed in the changing sector of education. A bibliometric analysis and thorough literature review of AR in vocational education research from 2003 to 2023 will provide insights. Data is visualized via VOSviewer and Tableau. Bibliometric trends in publication count, impact, research focus, and subject area are examined in this paper. Systematic assessment of learned skills is also included. The quantitative distribution of publications is growing annually and is projected to continue. Citation patterns reveal a large increase in research outputs, although not all of them are revolutionary or impactful. Research focus is divided into 6 clusters. Cluster 1 studies industrial architecture, Cluster 2 biomedical surgery, Cluster 3 product development and smarter manufacturing, Cluster 4 learning methods, Cluster 5 AR's positive impact, and Cluster 6 learned skills. This review shows that AR improves several capabilities but occasionally sets back others. This article examines study findings on unknown subjects and talent appraisal, which is important but understudied. This research is essential for educational technology, vocational instructors, and educational institutions to advance AR in untouched field.

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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). Augmented Reality 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).

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.

To close the gap of previous research on AR in the field of vocational education that have not been widely discussed, this article aims to provide insights through bibliometric analysis and systematic literature review into the utilization of AR in subject areas that have not yet fully embraced, as well as shed light on the less explored abilities or skills acquired through AR usage. This review will provide valuable insights for researchers in the field of educational technology, vocational educators, and educational institutions to guide the advancement of AR in unexplored domains.

This article discusses developments in research of the development and integration of AR in vocational education. We will explore starting from publication trends in the last 20 years. The impact of citations and related keywords that intersect will be discussed. In the end, we will highlight what skills are gained from using AR and what tools are used for AR development. This research will contribute knowledge to considerations and a complete picture of the use of AR in vocational settings. The following are the research objective (RO) that will be answered in this article

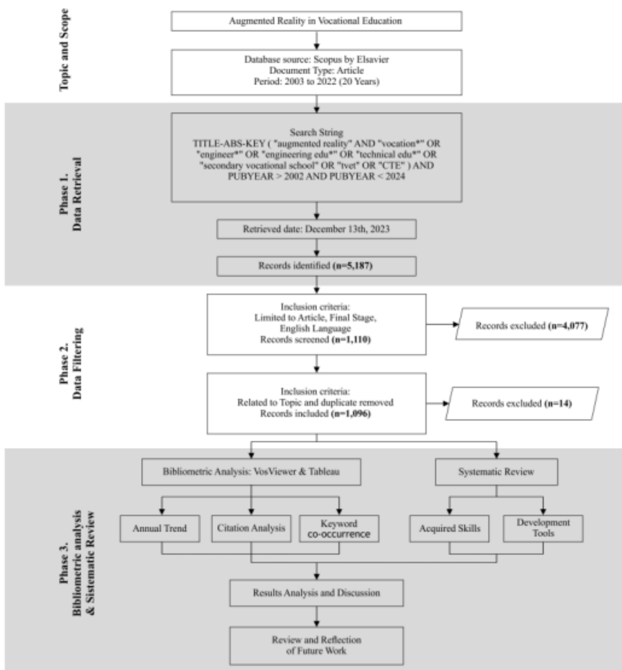
RO1	:	Analyze quantitative distributions of publications of AR application publication in vocational education
RO2	:	Reveal prevailing patterns of citation of AR application in vocational education
RO3	:	Map research focus about the use of AR in vocational education
RO4	:	Identify skills can be gained from using AR in vocational education
RO5	:	Reflect future work of AR development for vocational education

Research Method

This study employs a fusion of bibliometric analysis (BA) and systematic literature review (SLR) methodologies. 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).

Bibliometrics is a technique used to detect and organize scientific patterns and research (Vílchez-Román & Mauricio-Salas, 2021). The majority of bibliometric analyses typically rely on Thomson Reuters' Web of Science (WoS), PubMed, and Elsevier's Scopus as their main sources of data. The data source for this research was only obtained from the Scopus database. Scopus offers a broader and more prestigious scope of coverage compared to both Web of Science and PubMed (Falagas et al., 2008, Mongeon & Paul-Hus, 2016, and Yeung, 2019).

Figure 1. Research Procedure



In Phase 1, the search criteria are defined to identify records in the Scopus database. Vocational education has a lot of terminology and has many abbreviations. Based on the results of previous literature studies, vocational education can be termed engineering education, technical education, secondary vocational school, technical and vocational education (TVET), and Career in Technical Education (CTE). These terms then become part of the search string to be able to capture more complete publications. 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, the documents undergo a filtering process based on specific inclusion criteria.

1) The document is an article and not a conference paper, book chapter, review, conference review, editorial, book, note, letter, erratum, short survey, retracted, data paper;
2) The document is in english and not other language;
3) The document is related to topic mentioning AR and vocational education (or similar terms);
4) In the case of duplicate documents, one is taken from the primary source.

At this stage, the documents included and according to the inclusion criteria for further research were 1,096 documents

Subsequently, in Phase 3, the document was exported to the VOSviewer program (Version 1.6.19) and Tableau Desktop (Version 2023.3.0 Professional Edition) to carry out bibliometric analysis on the total number of publications each year and citation analysis, thereby enabling data visualization. Based on the collected documents, a systematic review was then carried out using a point extraction approach into an informative table. Extraction focuses on investigating acquired skills and various AR development tools in vocational education. The final step entails data analysis to ascertain the main themes explored in the research undertaken on AR in vocational education. All findings are then synthesized and reflected upon as a form of evaluation and insight for further research

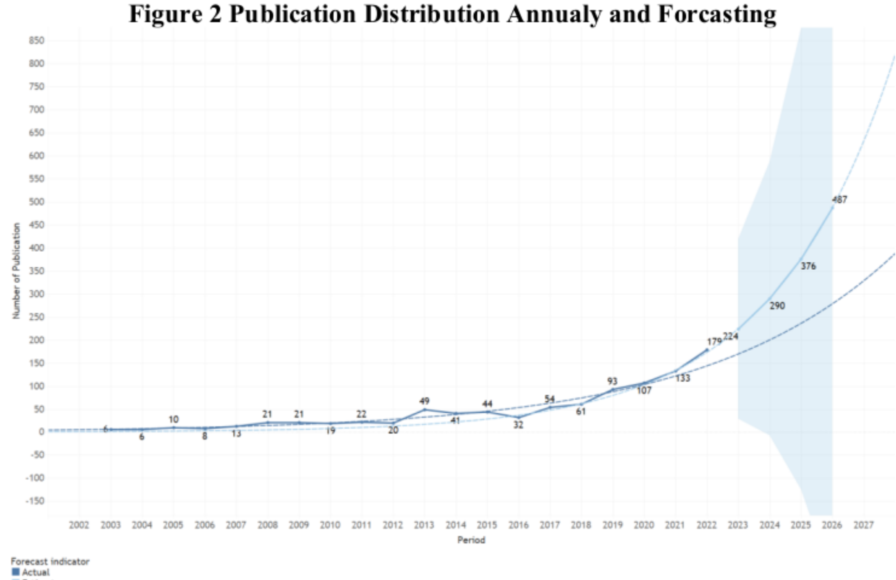
Result and Discussion

Publication Trend

Quantitative Distributions of Publications

The research trend in AR in vocational education is steadily growing annually. Figure 2 illustrates the frequency distribution of the number of publications per year, using a sample of 1,096 papers that satisfy the inclusion requirements. 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 2 Publication Distribution Annualy and Forcasting



AR technology was first proposed in 1968 by computer scientist Ivan Sutherland at Harvard. Sutherland, often referred to as the "father of computer graphics," developed an AR head-mounted display device. In subsequent decades, laboratories, universities, enterprises, and national agencies made further progress in the development of AR for wearable devices and digital displays (Wei & Yuan, 2023). The widespread development of new AR technology in the 2000s was facilitated by significant advancements in computing and visual processing, which greatly enhanced its feasibility (Chatzopoulus et al., 2017).

The surge in interest in AR research in the vocational education area commenced about 2010, coinciding with the introduction of AR application technologies on mobile platforms in the early 2010s (Nath, 2018). Various technical variables that accelerate the advancement of AR technology include:

1) Graphics processing advancement: As technology has advanced, particularly in areas like computer vision, graphics processing, and sensor capabilities, AR experiences have become more immersive and realistic. High-performance devices, such as smartphones and AR glasses, contribute to delivering compelling AR experiences (Abrash, 2021; Qiao et al., 2019);
2) Mobile Devices and Apps: The widespread adoption of smartphones equipped with cameras, sensors, and powerful processors has democratized AR (Kuntz et al., 2018). Mobile devices serve as accessible platforms for AR applications, making it easy for users to experience AR without the need for specialized equipment;
3) Developer Tools and Platforms: The availability of user-friendly AR development tools and platforms has played a crucial role. Companies like Apple (ARKit) and Google (ARCore) provide SDKs (Software Development Kits) that make it easier for developers to create AR applications (Linowes & Babilinski, 2017). This has lowered the barrier to entry for developers, fostering a growing ecosystem of AR apps.

AR holds the potential to revolutionize vocational learning and industrial practices by substituting or complementing traditional tools. Through AR, remote assistance becomes feasible, allowing experts to provide real-time guidance, reducing the need for physical presence and associated costs (Moourtzis et al., 2020). AR-based training simulations create realistic, cost-effective environments for hands-on skill development, eliminating the requirement for expensive equipment. In industrial applications, AR assists in equipment maintenance, repair, and inspection, minimizing downtime and improving overall efficiency (Sattarpanah et al., 2022). Safety training benefits from AR simulations of hazardous scenarios in a controlled environment (Li et al., 2018). Additionally, AR facilitates the assembly process on manufacturing lines, reduces physical tool requirements, aids in design visualization, and enables customized learning experiences (Moutzis et al., 2019). By integrating AR, organizations can optimize resource utilization, enhance training efficiency, and achieve cost savings while transforming vocational education and industrial practices (Jetter et al., 2018).

AR promotion in vocational education can be driven by educational institutions, industry stakeholders, and government authorities aiming to improve workforce competencies and align with technological progress (Hendra et al., 2023). AR entails superimposing digital content, such as photographs, movies, or 3D models, over the physical surroundings, resulting in an engaging and immersive encounter. Within the realm of vocational education, this technology can be utilized for the implementation of training programs, workshops, and skill-enhancement activities. Collaborations between technology developers, educators, and industry professionals are essential in driving the adoption of AR in vocational training and ensuring its alignment with industry needs.

Based on the analysis of the trend in publications, research on AR in the field of vocational education is projected to continue its upward trajectory in the next two years. The estimated prediction confidence level stands at 95%. This suggests a growing interest and recognition of the potential benefits that AR can bring to vocational education. As technology

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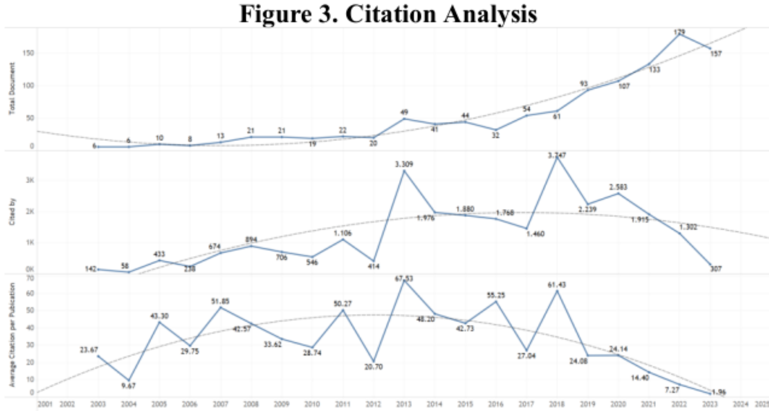
continues to advance, educators and researchers are likely to explore innovative ways to integrate AR into vocational training programs, enhancing the learning experience for students and preparing them for real-world challenges. The high confidence level in this prediction underscores the belief in the sustained growth and significance of AR applications in vocational education over the specified timeframe.

Prevailing Patterns of Citation

Publications are grouped according to year of publication and then analyzed for total citations and average citations per publication (Figure 3). 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 3. 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 groundbreaking 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.

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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 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 4. displays the network representation of the keyword.

Figure 4. Keyword Network Visualization

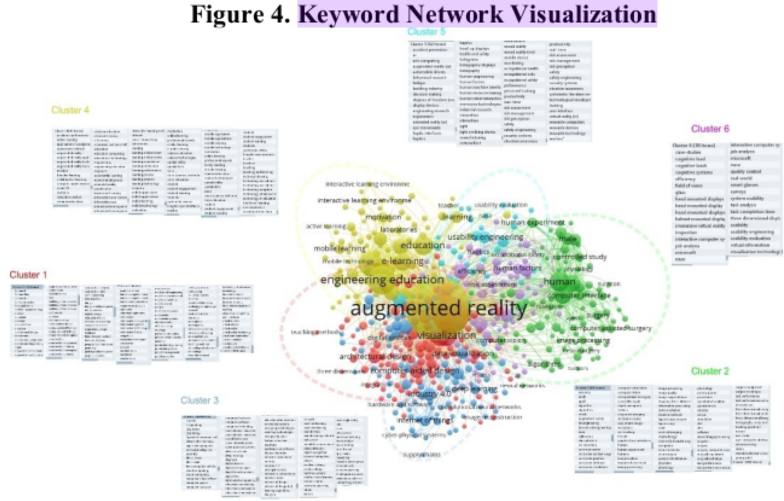

Figure 4 illustrates the emergence of keywords and the relationship between one keyword and other keywords. The size of the circle for each keyword indicates how often the keyword appears in the collected documents. Keyword analysis is divided into 6 clusters. Each cluster has a special theme that is interrelated.

Cluster 1 contains 122 keywords. The most dominant keywords are: virtual reality, visual, construction industry, architectural design, and computer aided design. The link between the keywords augmented reality (AR) and the keyword clusters virtual reality (VR), visual, construction industry, architectural design, and computer-aided design (CAD) lies in the integration of these technologies to bring about a profound transformation in the construction and design industry architecture. Combining AR and VR, professionals in this industry can create more immersive and interactive visual experiences, allowing them to incorporate architectural design elements from CAD into virtual environments or embed them in the physical world through AR (Flavián et al., 2019; Banfi, 2021; Solanki et al., 2023). Thus, construction projects can be simulated in real-time with a high level of detail, allowing experts to check designs, detect potential problems, and make better decisions before moving to the physical construction stage (Hasjirasouli et al., 2022; Kolaei et al. al., 2022; Rajaratnam et al., 2022; Ramos-Hurtado et al., 2022). The integration of AR and VR with CAD creates powerful tools for modeling, visualization and collaboration in the construction industry, bringing efficiency and innovation to the project planning and execution process.

Cluster 2 contains 85 keywords. The most dominant keywords in this cluster include: “human”, “article”, “procedures”, “biomedical engineering”, “surgeon”, and “neosurgery”. The integration of augmented reality (AR) with the keyword clusters human, article, procedures, biomedical engineering, surgeon, and neosurgery marks a revolutionary development in the field of biomedical surgery. In this context, AR provides the ability to visualize relevant information directly on the surgical field, giving the surgeon a real-time view during the procedure. Scientific articles on AR in surgery discuss how this technology can improve the precision and success of surgical procedures by providing accurate visual navigation (Al-Gailani et al., 2022). Involving biomedical engineering technology, AR helps integrate patient data into a visual display, enabling surgeons to make better informational decisions (Cofano er al., 2021). In doing so, surgeons can improve efficiency, safety, and patient outcomes in the context of neosurgery, creating a surgical environment that is increasingly sophisticated and connected to science.

Cluster 3 contains 84 keywords. The most dominant keywords in this cluster include: “artificial intelligence”, “internet and things”, “data visualization”, “product design”, and “manufacturing”. The integration of AR with the keyword clusters artificial intelligence (AI), internet of things (IoT), data visualization, product design, and manufacture open new opportunities in product development and smarter manufacturing. By leveraging artificial intelligence and IoT, AR can provide interactive visual experiences connected to data and physical devices in real time (Devagiri et al., 2022). Combining AR with data visualization allows designers and engineers to present complex information in an easy-to-understand way, speeding up the product design process. Additionally, in the manufacturing stage, AR can be used for worker training, ensuring efficient production processes, and monitoring machine performance in real-time (Olshannikova et al., 2015). Thus, the integration of AR with AI, IoT, data visualization and product design technologies provide a solid foundation for a paradigm shift in the manufacturing industry, creating a connected, intelligent, and innovative environment.

Cluster 4 contains 83 keywords. In this cluster, the most dominant keywords include: “engineering education”, “students”, “e-learning”, “motivation”, “engineering”, and “vocational education”. The use of AR in the context of engineering education and vocational education marks a significant breakthrough in learning methods, especially for students in the engineering field. To increase student motivation and engagement, AR can provide a more interactive and immersive learning experience. By presenting engineering concepts visually and realistically, students can more easily understand the material, relate it to practical contexts, and develop their skills (Takrouri et al., 2022). An e-learning approach that utilizes AR also allows more flexible and independent access to learning materials, enriching the student learning experience (Alzahrani, 2020). In addition, the use of AR in the context of engineering education prepares students for real-world challenges by providing situational simulations and virtual practicums that can improve their practical skills. Thus, AR provides a revitalization impetus for vocational education and engineering education, leading to increased student motivation and learning achievement in the engineering field.

Cluster 5 contains 62 keywords. In this cluster, the most dominant keywords include: “situation awareness”, “personnel training”, “safety engineering”, “decision making”, “accident prevention”, and “human engineering”. The integration of AR in this keyword clusters illustrates the positive impact of this technology in improving situational understanding, personnel training, and security in an engineering context. AR can provide a higher level of situational awareness by presenting important data and information directly to

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operators or personnel, enabling faster and more informed decision making (Woodward & Ruiz, 2022). In personnel training, AR provides realistic and interactive simulations to train operational and situational skills, increasing personnel readiness in dealing with critical situations. Regarding safety engineering, AR can provide information about potential risks directly in the field, providing proactive solutions for accident prevention (Alirezaei et al., 2022). In the context of decision making, AR can provide visual and contextual support to decision makers, facilitating more comprehensive analysis (Martins et al., 2022). Thus, the use of AR in this cluster makes a positive contribution in encouraging safety engineering, increasing situational awareness, and strengthening personnel capabilities to prevent accidents and increase operational efficiency.

Cluster 6 contains 30 keywords. In this cluster, the most dominant keywords include: “efficiency”, “inspection”, “task completion time”, “task analysis”, “job analysis”, and “usability engineering”. The connection between AR and keyword clusters such as efficiency, inspection, task completion time, task analysis, job analysis, and usability engineering illustrate the positive impact of this technology in improving operational efficiency and task analysis. AR provides the advantage of increasing efficiency by presenting information directly related to the work context, minimizing distractions, and enabling workers to complete tasks more quickly (Marino et al., 2021). In the inspection context, AR facilitates task analysis by providing real-time visualization and interactive guidance, speeding up the inspection process and minimizing errors. Task completion time can be shortened because AR provides direct visual support that helps workers carry out tasks more effectively. In addition, task analysis and job analysis can be improved through the implementation of AR, which provides better visibility and understanding of the complexity of work tasks (Lee, 2020; Abhari et al., 2014; Sirakaya & Kilic, 2018; Borgen et al., 2021). Within a usability engineering framework, AR can be designed to ensure an intuitive and easy-to-use interface, increasing worker engagement with the technology (Marino et al., 2021). Therefore, integration of AR with such clusters brings increased efficiency, task understanding, and usability, creating a more effective and productive work environment. Skills acquired with the help of AR will be discussed further in this article.

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%

Subject Area	Documents	Percentage
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%
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%

The predominant presence of documents in engineering, computer science, and social sciences suggests that these fields have been at the forefront of incorporating AR into vocational education. These disciplines likely benefit from the technological and interactive aspects of AR, fostering innovation and research in engineering and computer science, while the social sciences explore the broader implications of AR in educational contexts. Conversely, the absence or lower representation of documents in subject areas such as Agricultural and Biological Sciences, Economics, Econometrics and Finance, Immunology and Microbiology, Nursing, Pharmacology, Toxicology and Pharmaceutics, and Dentistry indicates potential areas for future exploration and research. The lack of focus in these subjects might be due to the specific nature of vocational education in these fields or the perceived challenges in integrating AR into these contexts (Wu et al., 2013).

Addressing these gaps could lead to a more comprehensive understanding of the potential applications and benefits of AR across diverse vocational fields. Researchers and practitioners in vocational education within these less-explored subject areas may find opportunities to innovate and enhance learning experiences through the strategic integration of AR technologies. In summary, the distribution of documents across subject areas in AR research within vocational education points towards the need for a more inclusive and interdisciplinary approach. By addressing the underrepresented subject areas, researchers can contribute to a more holistic understanding of the role AR plays in advancing vocational education across a broader spectrum of 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 freshmen	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 (Ms. Hololens)	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	/
Gargrish et al., 2021	80 polytechnic	Mathematic	AR-based GLA	memory retention abilities	/

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Author	Respondent	Field Area	Tools	Acquired Skills	Effect
	students				
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 student	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	/ /

Author	Respondent	Field Area	Tools	Acquired Skills	Effect
				abilities	/
Wyss et al., 2022	18 student teachers for science and technology for lower secondary schools	Teaching	AR-supported teaching unit, Ms. Hololens	self-eficacy motivation	/ /
Omar et al., 2019	30 engineering students	Mechanical Engineering	AREDApps	orthographic engineering drawing skills	/ /
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 app	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	/
Wong et al., 2021	50 engineering students	Engineering	ARVR	spatial ability	/
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	/ /
Purwaning-tyas et al., 2022	Radar laboratory students	Aviation	ARVR	troubleshooting capability	/

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Author	Respondent	Field Area	Tools	Acquired Skills	Effect
Al-Gailani et al., 2022	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	/
Yang et al., 2023	Acritecture vocational students	Architecture	AR-Based	engineering drawing	\

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 (Akçayır et al., 2016; Singh et al., 2019), spatial abilities (Martín-Gutiérrez et al., 2010; Deshpande & Kim, 2018; Kwiatek et al., 2019; Urbano et al., 2020; Tuli et al., 2022; Weng et al., 2023; Wong et al., 2021), assembly skills (Sirakaya & Kilic, 2018; Han et al., 2022; Rohidatun et al., 2017), critical thinking (Faridi et al., 2021; Dutta et al., 2023), memory retention abilities (Gargrish et al., 2021), knowledge retention (Borgen et al., 2021), collaborative learning (Vassingh et al., 2020), furniture carpentry skills (Lee, 2020), 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.

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In conclusion, the extensive range of skills positively affected by AR in vocational education underscores its potential as a transformative tool. The variations in effectiveness highlight the importance of carefully considering the specific context and learner characteristics when implementing AR in educational settings. The integration of AR into education presents a series of obstacles, specifically in the areas of learning models and contextual integration.

Reflection and Future Work

The findings regarding the promising benefits of AR in vocational education underscore the transformative potential of this technology in shaping the future of learning and skill development. The rise in publications reflects the growing interest and investment in digital technologies across various domains. The alignment of AR promotion with educational institutions, industry stakeholders, and government authorities highlights a collaborative effort to enhance workforce competencies and keep pace with technological progress. The projection of a continued upward trajectory in AR research within vocational education suggests a sustained commitment to exploring and harnessing the potential of AR in the coming years. The proportional increase in citation impact indicates the impact of diverse research efforts, incremental progress, and the expanding but dispersed body of knowledge in this field.

Untouch Subject Area

However, the identified untouched areas, particularly in subject areas such as Agricultural and Biological Sciences, Economics, Econometrics and Finance, Immunology and Microbiology, Nursing, Pharmacology, Toxicology and Pharmaceutics, and Dentistry, present avenues for future exploration. Researchers can contribute to a more holistic understanding of AR's role in advancing vocational education across a broader spectrum of disciplines. The recognition of potential discrepancies between AR applications and conventional learning methods highlights a critical obstacle. The transition from traditional teaching to AR-based approaches necessitates a careful reassessment of pedagogical strategies, emphasizing the importance of addressing these challenges in the integration process. This is also highlighting the need of conceptual framework of pedagogical strategic in utilizing AR into vocational learning.

Uncover & Measure Future Skills

The meticulous analysis of the data on AR integration in vocational education reveals a nuanced and multifaceted impact on a broad spectrum of skills. This comprehensive understanding emphasizes the need for a reflective and forward-looking approach to guide future research endeavors. The identification of increased effectiveness in certain skills alongside occasional decreases raises critical questions about the nature and contextual factors influencing AR's impact. This calls for a reflective exploration into the intricacies of AR implementation, considering not only the positive outcomes but also the potential challenges and drawbacks associated with specific skills. Such reflection is essential for refining instructional strategies and optimizing the benefits of AR in vocational education.

A vital avenue for future research involves conducting a thorough examination of AR effectiveness in cultivating industry-specific competencies, particularly with a focus on essential employability attributes that promote industry sustainability. In response to the evolving workforce landscape, characterized by dynamic shifts and a growing demand for skills beyond technical proficiency, research initiatives should closely collaborate with industries to identify the precise competencies sought after in various sectors (Hernandez-de-Menendez et al., 2020). This targeted exploration of how AR interventions can effectively bridge skill gaps within specific professions, especially in the context of sustainability, ensures a finely tuned approach that aligns with industry or job-specific requirements.

Future research initiatives should collaborate closely with industries to identify precise competencies sought after in various sectors, enabling a targeted exploration of how AR interventions can effectively bridge skill gaps within specific professions. This industry-tailored approach ensures that AR technologies contribute not only to general skill enhancement but also to the cultivation of job-specific capabilities, meeting the evolving needs of diverse professional environments and enhancing workforce readiness and performance. Many regions and countries consider the development of a green economy, which emphasizes the integration of environment and development, as a forward-looking approach. Therefore, it is crucial to incorporate green skills into vocational and professional education as essential competencies (Pavlova, 2017). By combining AR technologies with green skill development, researchers can contribute to not only enhancing general skills but also fostering eco-friendly practices and sustainability within diverse professional environments, ultimately promoting workforce readiness and performance.

Furthermore, assessing the effectivity of skills acquired through AR applications requires a sophisticated methodology. Adopting a meta-analysis process can provide a comprehensive and systematic approach to evaluating the overall impact (Borennstein et al., 2021). Measuring the effect size allows for a quantitative understanding of the magnitude of AR's influence on skill development. This process not only aids in synthesizing diverse research findings but also helps identify moderator variables or factors influencing the outcomes (Gurevitch et al., 2018). Understanding these moderating factors is crucial for optimizing the use of AR in vocational education settings.

Future work endeavors should embrace a reflective stance, acknowledging the dual nature of AR's impact on skills. The emphasis should be on probing deeper into the effectiveness of AR in cultivating a diverse range of skills, especially those pertaining to employability and sustainability. The adoption of a meta-analysis process can serve as a powerful tool for refining our understanding and uncovering the nuanced dynamics that influence the outcomes of AR integration in vocational education. This reflective and research-driven approach will pave the way for more informed and effective utilization of AR technologies in shaping the future of vocational learning.

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Conclusion

The promising benefits of AR in vocational education settings are evident, as reflected in the escalating number of publications and the diverse array of disciplines embracing AR applications. The analysis of publication trends projects a continued upward trajectory in AR research within vocational education over the next two years, marked by a proportional increase in citation impact. The identified clusters of research focus, spanning construction and design, biomedical surgery, product development, learning methods, positive impacts, and acquired skills, underscore the breadth of AR's influence. While engineering, computer science, and social sciences dominate the landscape, the lower representation in certain subject areas points towards untapped potential for future exploration. The multifaceted impact of AR on skill acquisition, with positive trends in various competencies but occasional declines in specific areas, emphasizes the need for nuanced assessments. This prompts a call for measuring the effectiveness of AR in developing skills crucial for sustainability and employability through rigorous meta-analysis processes, which can unveil moderating variables optimizing AR's utility in vocational education. This comprehensive understanding paves the way for informed strategies in harnessing AR's potential to shape the future of vocational education.

Recommendation

In advancing research on AR in vocational education, it is crucial to pursue several key areas. First, future studies should investigate the development of comprehensive pedagogical frameworks tailored to AR-based learning, ensuring that the integration of this technology aligns with educational objectives and industry standards. Collaboration with industry stakeholders will enable a deeper understanding of the specific skills required for the evolving workforce, especially those related to sustainability and green skills. However, barriers such as the potential high cost of AR technologies, lack of infrastructure, and resistance from educators accustomed to traditional teaching methods must be addressed. Additionally, research should explore the long-term effectiveness of AR applications in skill retention and employability, with a particular focus on meta-analytical approaches that quantify AR's impact across diverse disciplines. Addressing these challenges will ensure that AR's full potential in vocational education is realized, bridging gaps between educational outcomes and industry needs.

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