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Modern learning paradigms: A bibliometric analysis of augmented reality and virtual reality in vocational education

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Abstract: This bibliometric analysis aims to explore the publication trends of the last decade, especially on modern learning paradigms that focus on implementing Augmented Reality (AR) and Virtual Reality (VR) in vocational education. This research specifically addresses the analysis of current technology trends, gaps, challenges, strengths, and opportunities of AR and VR during (2015-2024). This research method uses the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)" protocol to collect data from publications focusing on high-quality research results. Data acquisition was analyzed and identified using MS Excel software and VOSciewer to visualize various critical metadata obtained in the Scopus database. Notably, publication trends and distribution patterns, the contributions of authors, the geographical spread of publications, and the identification of significant publication sources are all essential for analyzing the opportunities and challenges within the context of vocational education. The results of this study identified an augmenting growth of publication trends from 2015-2023, including the country of origin of prominent authors such as Bacca et al. (Spain), Babu et al. (India), and Lerner et al. (Germany), whose research results have been proven to impact the primary reference in the field of vocational education in the utilization of AR and VR. It is widely cited and has become the primary reference for other authors. Consequently, this bibliometric-based research underscores the potential of AR and VR technologies to improve vocational education by enhancing motivation, educational access, personalized learning, collaboration, and reducing operational costs.

Keywords: Media technology; TVET; Emerging technology; Publication trends

1. Introduction

The development of science and technology in the industrial era 4.0 includes a variety of creativity and innovation in changing the pattern of human life at work (Gajdzik & Wolniak, 2022; Sima et al., 2020). Notably, integrating these technologies encourages access to relatively modern education and improves the quality of learning in vocational education. Moreover, the emergence of accelerated digitalization, especially in vocational education, encourages many teachers and researchers to strengthen learning accessibility by providing a more immersive and interactive learning experience (Mhlongo et al., 2023; Timotheou et al., 2023). Accordingly, one of the emerging technologies in this decade is Augmented Reality (AR) and Virtual Reality (VR), which are technologies that are often utilized as learning media by creating a digital environment interactively in overcoming conventional learning gaps (AlGerafi et al., 2023; Childs et al., 2023; Xiong et al., 2021). These technologies are considered innovations with promising future novelty values targeted for overall evaluation.

However, research indicates that certain contemporary controversies associated with adopting AR and VR technologies face specific constraints and difficulties, primarily in funding and execution (Criollo-c et al., 2024; Samala et al., 2023). For example, a survey of vocational education research shows that most schools and educational institutions do not have the resources to use AR and VR technologies (Raji, 2019; Scheid, 2018). Additionally, there are concerns about the ability and skills of teachers to incorporate these technologies into the curriculum. Conversely, despite these limitations, there are promising opportunities to integrate these technologies, primarily through cooperation between private-sector partnerships and industries with resources that schools and educational institutions can expertly utilize. Thus, this concern can be overcome by working together to gain access to AR and VR technologies at a more affordable cost and access to specialized training in implementing these technologies in the vocational education sector (Scheid, 2018; Soliman et al., 2021).

Augmented Reality (AR) is a technology that integrates digital components with the physical world, typically through visualizations displayed on a smartphone (Samala et al., 2024). When the smartphone's camera employs a tracking system, either Marker-based or Markerless, it can generate a 3D object within the natural environment (Fortuna et al., 2023; Samala et al., 2024; Waskito et al., 2024). For instance, When students direct their smartphone cameras toward a textbook fequipped with AR technology (Prasetya et al., 2024), they can see 3D objects appear, which deliver information through animations to clarify vocational learning concepts. This integration of Augmented Reality technology in vocational education is demonstrated in Figure 1.

Figure 1. Augmented reality using smartphones in vocational education

Subsequently, the utilization of Virtual Reality in the realm of vocational education is described as a technology that combines digital elements with the real world, allowing users to see a variety of interactions that are more immersive, interactive, and simulative (Pellas et al., 2021; Radianti et al., 2020). In a way, the benefits of this technology are no less critical than Augmented Reality, as

Virtual Reality provides many exciting offerings in terms of a more realistic and real-time learning experience (Remolar et al., 2021). Notably, VR allows learners to actively engage in real-world simulations without having to be in the actual physical environment, so this technology provides various opportunities for users to learn more practical skills in a more controlled and safe virtual environment for both face-to-face and online learning (Prasetya, Fajri, et al., 2023; Prasetya, Fortuna, et al., 2023; Refdinal et al., 2023). Additionally, VR can simulate more complex learning scenarios that are risky to replicate in reality. For instance, in mechanical engineering training or the medical field, VR can train students in highly skilled situations without posing risks to equipment or individual safety. This benefit can help improve students' competence and confidence before they move on to real-world practice. The use of this technology can be seen through the demonstration results of the Oculus Rift device in Figure 2.

Figure 2. Virtual reality utilizing oculus rift in vocational education

These technologies offer great potential in the future, especially in vocational education, which focuses on developing learners' practical skills (Ahmad, 2020; Spöttl & Windelband, 2021). On the one hand, this technology provides a work simulation picture that is relevant in training students' competencies to enter industries requiring high accuracy and work safety, such as engineering, engineering, automotive, information technology, health care, or construction. Overall, the output of vocational education is designed to fulfill the needs in the world of work with the best quality of human resources, skills, and extensive knowledge and insight needed to achieve their career targets in the future.

Nevertheless, while many studies have identified and evaluated the effectiveness of AR and VR in general education, there is still a lack of information regarding implementing these technologies, particularly in vocational education (Alalwan et al., 2020). The development of AR and VR applications has a fundamental role in understanding publication trends, collaborations, contribution impacts, and challenges and gaps of the most prominent research topics in this context (Zhang et al., 2020). More profound identification of shortcomings, strengths, and potential for further development is carried out through bibliometric analysis mapping the latest scientific publication trends in the last decade (Guray & Kismet, 2023; Majid et al., 2024).

In order to obtain accurate and precise analysis results, this research focuses on examining research topics on the use of AR and VR in vocational education, including analysis of publication frequency, collaboration between research and institutions, keyword analysis, and how the results of the geographical distribution of this research in the form of network visualization. In addition, the assessment of gaps in the literature obtained based on the data collection results will be further explored from the perspective of opportunities and recommendations for future research so that these benefits can improve the integration of AR and VR in vocational education. Accordingly, the results of the formulation of recommendations through the findings of this bibliometric research provide valuable insights for educators, researchers, and practitioners of vocational education in utilizing AR and VR technology optimally and improving the quality and effectiveness of vocational learning to be more innovative. Overall, this study succeeded in formulating several research questions to be answered by this study in achieving the research objectives, namely:

RQ1. What are the top publications cited in augmented and virtual reality-based learning in vocational education over the past decade, and what is the distribution of publications by subject area?
RQ2. What are the trends and distribution of publications related to AR and VR in vocational education, and what countries contribute the most and are the most relevant publication sources?
RQ3. Who are the top 10 prolific authors contributing to research on AR and VR in vocational education?
RQ4. What are the main gaps and challenges identified through the main keywords in using AR and VR in vocational education?
RQ5. How do AR and VR technologies' strengths and opportunities impact vocational training and learning?

Establishing the target of several questions in achieving this research's objectives is expected to provide in-depth insights related to the potential development of AR and VR in improving vocational education. It can guide curriculum developers, researchers, and policy designers in making vocational education more relevant.

2. Methods

Research procedure and design

This study aims to explore research publication trends in the last decade from 2015-2024, especially in modern learning that focuses on identifying publication trends and distribution, research gaps, and challenges in using Augmented Reality and Virtual Reality in vocational education. This study utilizes the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach (Page et al., 2021), which provides a systematic framework for identifying research gaps, screening, eligibility, and reporting data findings, as well as providing deeper insights into the use of these technologies using bibliometric analysis.

Furthermore, this study presents a detailed research procedure with several stages. Firstly, data collection is based on relevant academic sources, especially when retrieving data from the Scopus database. Besides, the data collected was filtered based on inclusion and exclusion criteria, with an appropriate research focus for analysis. After that, the results of the publication screening were analyzed bibliometrically to identify trends in the research literature, particularly on AR and VR in vocational education. Most importantly, it determines the distribution of publications in terms of yearly growth and then identifies the topics covered in the literature using the most commonly used keywords, thus helping to explore research gaps and challenges. Ultimately, this stage is the most crucial, mainly when the bibliometric analysis results have been successfully displayed; it is imperative to interpret them to offer recommendations for future research, including identifying the strengths and opportunities, as well as exploring the potential for further development of AR and VR in vocational education, thereby creating relevant strategies for the future. Additional insights into this bibliometric research process are visually depicted in the flowchart in Figure 3.

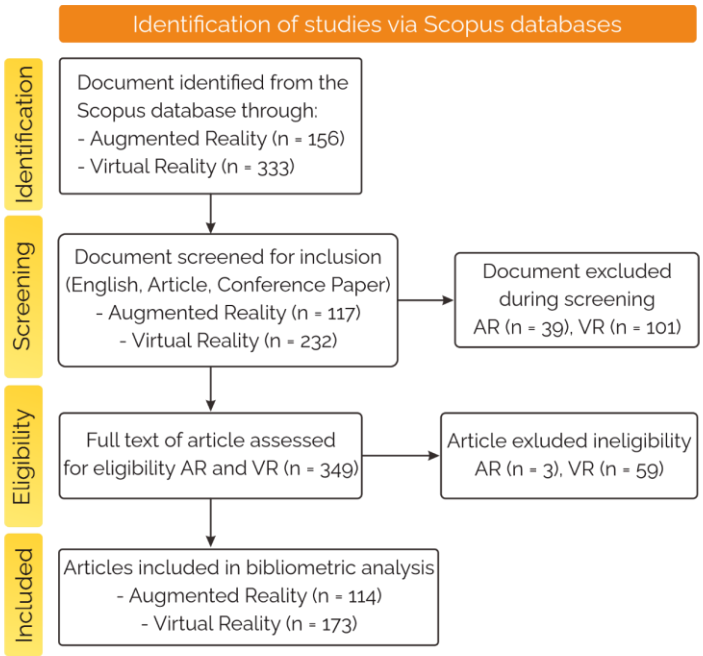

Figure 3. Flowchart for identification and screening of publication sources

Data dollection

The data was collected based on the highly reputable international academic database Scopus, using keywords related to "Augmented Reality," "Virtual Reality," and "Vocational Education." The data collected includes information about the publication, such as title, author name, institution, country, journal name, year of publication, and research abstract. For further details, the data collection for this study is in Table 1.

Table 1. Details of information from bibliometric data collection

Database from Scopus	
Keyword search: Augmented Reality	**Keyword search: Virtual Reality**
(TITLE-ABS-KEY (augmented AND reality) AND TITLE-ABS-KEY (vocational AND education)) AND PUBYEAR > 2015 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE, "conference paper") OR LIMIT-TO (DOCTYPE, "article")) AND (LIMIT-TO (LANGUAGE, "English"))	(TITLE-ABS-KEY (virtual AND reality) AND TITLE-ABS-KEY (vocational AND education)) AND PUBYEAR > 2015 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE, "article") OR LIMIT-TO (DOCTYPE, " conference paper")) AND (LIMIT-TO (LANGUAGE, "English"))
114 documents found	**173 documents found**
Duration (year): 2015 - 2024	
Data retrieval date: May 10th, 2024	

Data analysis technique

The data analysis technique in this bibliometric research uses descriptive analysis using MS. Excel software and VOSviewer, which is an application used to create visual maps of bibliometric data, such as citation networks, collaboration between authors, and keyword analysis in looking at current research gaps (McAllister et al., 2022). Citation network analysis helps to determine the relationships between publications through citation links, often focusing on the top 10 publications from reputable journals and the most cited articles from the last decade. Moreover, author collaboration analysis examines the contributions and partnerships among authors, focusing on AR and VR in vocational education. Finally, the keyword analysis uses VOSviewer to visualize the most commonly occurring keywords, providing a basis for interpreting research gaps and identifying opportunities for future studies in vocational education.

3. Results and discussion

Most cited publication types

RQ1. What are the top publications cited in augmented and virtual reality-based learning in vocational education over the past decade, and what is the distribution of publications by subject area?

This bibliometric research examines and reviews 114 papers on augmented reality and 173 papers on virtual reality, especially in vocational education, and information on the number of citations received in the last decade (2015-2024). The data collection results have been further identified based on inclusion and exclusion criteria by determining conference papers and articles to be the type of publication discussed in this study. The following is a visualization based on the types of AR and VR publications in vocational education depicted in Figure 4.

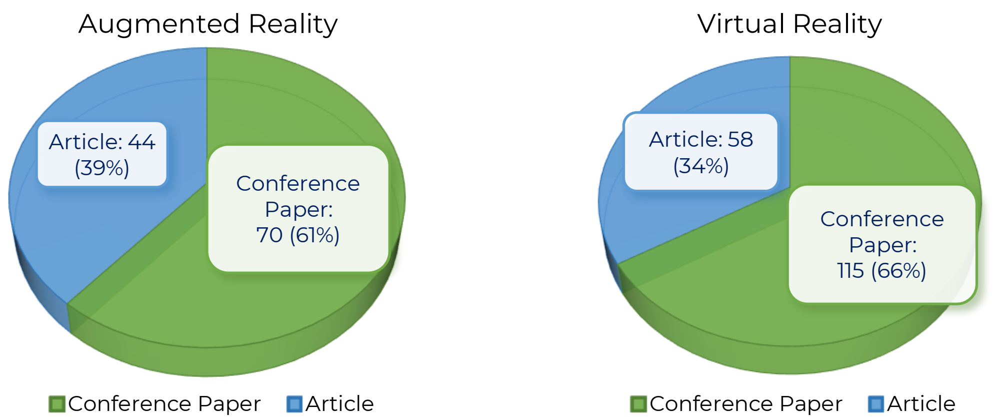

Figure 4. Type of publication: conference papers and articles (2015-2024)

The overall distribution of data obtained based on the use of technology in vocational education is visualized through Figure 4, which found the percentage of the use of Augmented Reality technology in a study (Article: 39%) and (Conference Paper: 61%). While the rate of Virtual Reality technology utilization in a study (Article: 34%) and (Conference Paper: 66%). Hence, AR and VR technology are used more in Conference Paper publications than in Articles.

In Table 2, there are publications utilizing Augmented Reality technology in vocational education with the type of publication in conference papers (70) and articles (44). In contrast, the findings we obtained from utilizing virtual reality technology in vocational education and the publication type in conference papers (115) and articles (58) show that the frequency of VR research types is higher than AR. However, the overall average distribution of AR publications (20.37) is relatively higher than VR (14.79), especially in conference papers and articles. Consequently, we conclude that the findings of many publications are not always the best. Nonetheless, good publications show their implementation and usefulness. For more details, we have summarized publications based on the type and distribution of data by considering all citations obtained, as presented in Table 2.

Table 2. Types of publications with the highest citation count data distribution

Publication type	Frequency		Number of citations		Average	
	AR	VR	AR	VR	AR	VR
Conference paper	70	115	444	368	6.34	3.20
Article	44	58	561	672	14.03	11.59
Total	**114**	**173**	**1011**	**1040**	**20.37**	**14.79**

Briefly, AR and VR have significant representation in vocational education research, with articles having higher citation averages than conference papers. These findings highlight AR and VR technologies' growing interest and impact in vocational education. Figure 5 presents a line graph depicting the publication trend of conference papers and Scopus database-indexed articles related to AR and VR in vocational learning from 2015 to the projection point in 2024, which is shown to significantly continue to increase based on the number of citations until 2023.

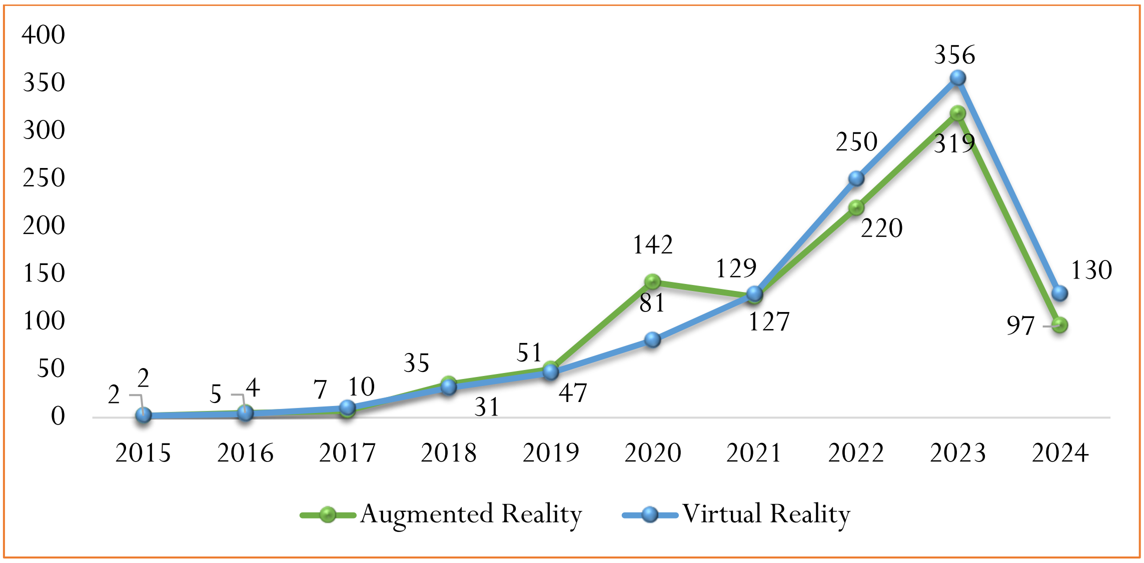

Figure 5. Average citation of all documents per year

Moreover, the trend of AR publications started modestly in 2015, with a negligible number of significant citations. Over the years, there was a marked increase, with a sharp rise around 2021, when AR publications began to outnumber VR publications. The peak comes in 2023, with AR reaching a significant 356 citations. Meanwhile, VR publications show a more consistent upward trend from 2015, starting with around ten significant citations. This growth continued steadily without dramatic spikes, peaking at around 319 significant citations in 2023. Similar to AR, VR publications are also projected to experience a substantial decline in 2024.

The graph shows that while AR and VR have become areas of increasing interest and research, AR has experienced a more volatile trend with sharper increases and projected decreases. In contrast, VR has maintained a more stable growth pattern. Meanwhile, the projected decline for both technologies in 2024 is due to various factors, such as shifting research priorities, technological advancements, and incomplete data, as we take the final tally to May 2024. Nevertheless, we still predict that the trend of educational research utilizing AR/VR technology will continue to rise in the next few years.

Moreover, besides outlining the various types of publications found in vocational education over the past decade, the subsequent analysis delves into the distribution of these publications by subject area based on prior research findings. The pie chart in Figure 6 illustrates the use of Virtual Reality across different academic fields, highlighting computer science as the dominant discipline in vocational education. The chart indicates the relative significance of each scientific field's utilization of Virtual Reality.

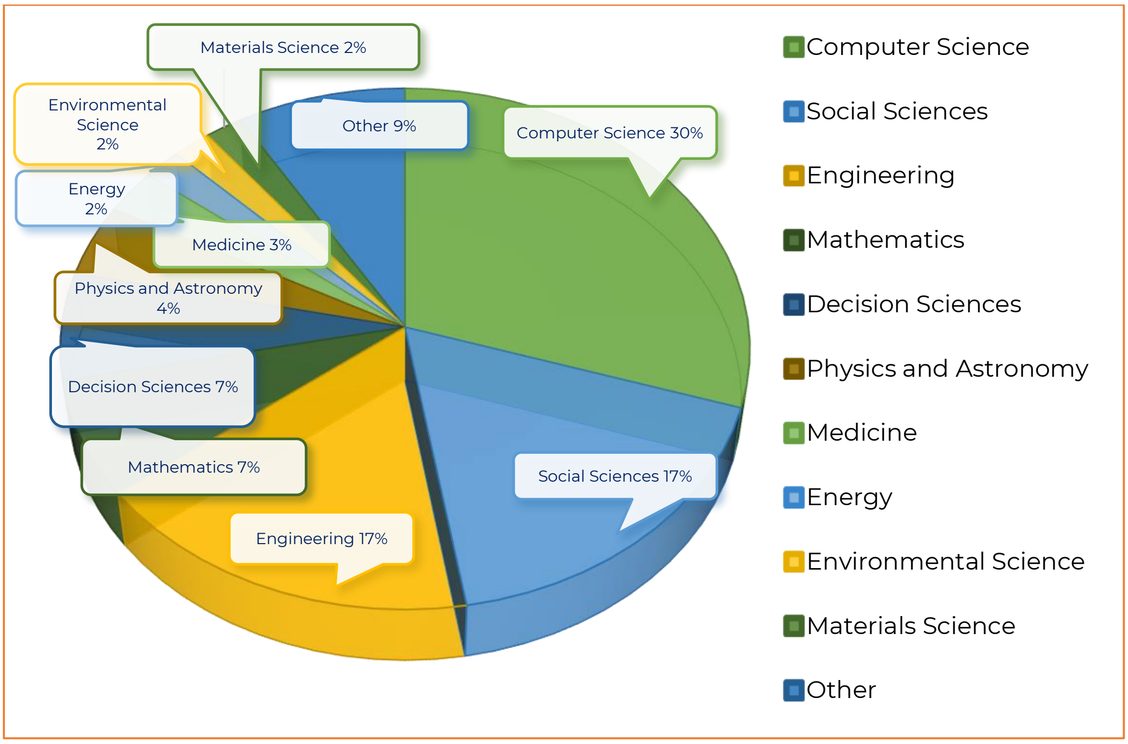

Figure 6. Proportion of VR utilization in each field of vocational education

In Figure 6, the proportion of Virtual Reality usage is dominated by "Computer Science" at 30%, which plays a fundamentally central role in developing and applying VR technology. After that, the fields of "Engineering and "Social Sciences" contributed 17% of VR utilization. This indicates that VR is crucial not only in engineering disciplines but also in the implementation of social research. On the one hand, other prominent fields, such as "Mathematics" and "Decision Sciences," both at 7%, show the engagement of these disciplines with VR for analysis and problem-solving purposes. On the other hand, the field of "Physics and Astronomy" represents 4%. In comparison, "Medicine" represents 3%, reflecting the growing impact of VR in scientific research and healthcare.

Although there are smaller proportions, especially in "Energy," "Environmental Science," and "Materials Science, with aspects of 2% each, which is assumed to indicate the specific implementation of VR in each of these fields, finally, the "Other" category includes fields that are not individually defined, however still contribute to the diverse VR application landscape. In summary, the pie chart underscores the interdisciplinary nature of VR, which has a significant impact ranging from the core computer science field to more outward applications such as engineering, social sciences, and other fields.

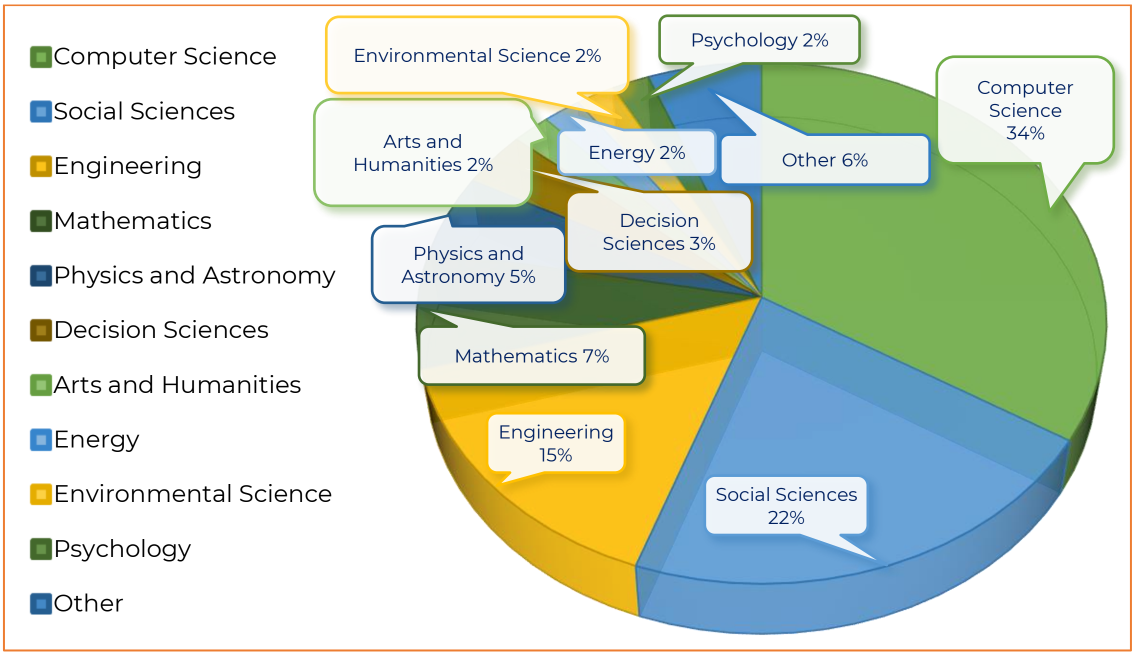

Figure 7. Proportion of AR utilization in each field of vocational education

Figure 7 depicts a visual representation of the utilization of Augmented Reality in various fields, especially the most dominating aspect, "Computer Science," with the most significant contribution of 34%, highlighting the leading role in the development of AR technology in vocational education. In addition, the application of AR in various sciences shows interesting variations; notably, "Social Sciences" occupies a composition of 22%, which reflects the significant integration of AR in fields such as psychology, sociology, and education, where this technology can increase access to learning to be more interactive and support the renewal of research on social behavior. The field of "Engineering" also has a leading role at 15%, reflecting the application of AR in design, simulation, and structured manufacturing processes.

Meanwhile, "Mathematics, Physics and Astronomy" has a more negligible contribution, with 7% and 5%, respectively, assuming these concepts have complex spatial relationships supporting education, learning, and research. The field of "Decision Sciences and Humanities Arts" weighs 4%, indicating that AR influences decision-making processes and the creative industry, where visualization and interaction play a fundamental role. Taken together, these and other fields indicate the potential for utilizing AR in the context of energy to improve efficiency across a wide range of disciplines that are not individually specified.

Trends and distribution of publication

RQ2. What are the trends and distribution of publications related to AR and VR in vocational education, and what countries contribute the most and are the most relevant publication sources?

The distribution of publication results is discussed in more detail by paying attention to the main trends related to Augmented Reality and Virtual Reality in vocational education from 2015 to 2024. The line graph in Figure 8 illustrates a diverse distribution each year, with the most significant growth in AR publications starting in 2015, which experienced a drastic increase until it reached a peak of around 20 publications in 2021-2022. This increase reflects the trend and interest in implementing AR in vocational education, which is quite popular as a learning tool.

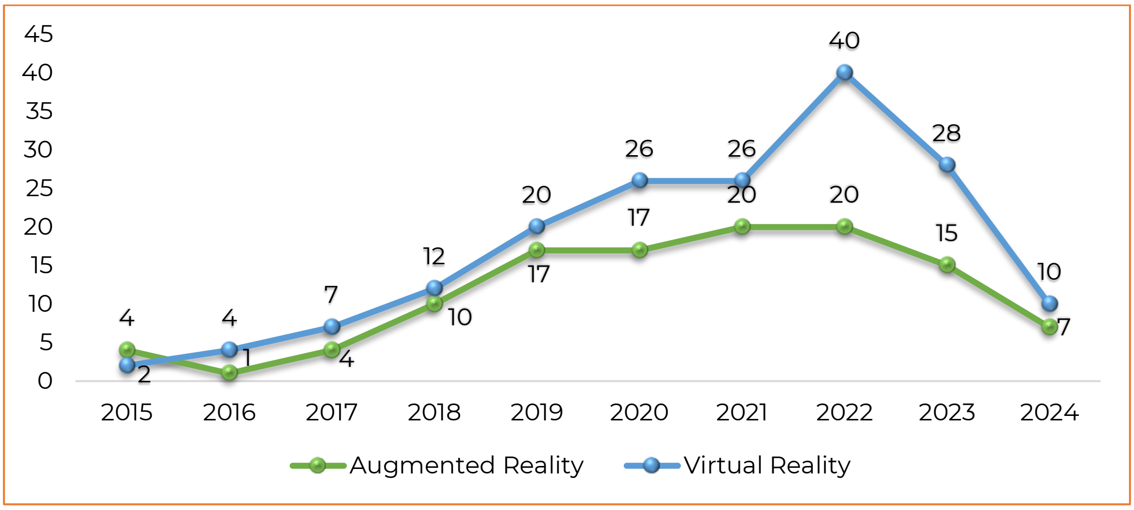

Figure 8. Distribution of publications in vocational education over the last decade (2015-2024)

On the contrary, the findings of VR publication results have increased steadily, with the highest point in 2022 with 40 publications, indicating the adoption of VR, which is quite popular to develop, especially after Covid-19 became the primary alternative for online-based learning in vocational education. In addition, the number of VR publications reached the same point at twenty-six in 2019 and 2020, indicating a steady interest before AR and VR publications started to decline in 2023-2024.

While both AR and VR technologies have become integral to vocational education, AR experienced a more steady increase and subsequent decrease in publications; however, it is predicted to rise again. Moreover, more publications on VR could be due to its earlier establishment as a tool for immersive learning experiences. However, on the other hand, the projected decrease in publications on these two technologies in 2024 is because the data used is still half a year old and will continue to evolve with the combination of integration in Metaverse, Artificial Intelligence, and Mixed Reality towards the renewal of new emerging technologies in vocational education.

Subsequently, in addition to discussing the distribution of publications, an interesting finding from our Scopus database represents the ten countries that contribute most to the utilization of augmented reality in vocational education. In Figure 9, the pie chart visualizes the data distribution of the most significantly contributing countries; firstly, Indonesia is the primary contributor, contributing 28% of AR technology, which essentially shows that Indonesia is utilizing AR technology quite a lot in vocational training and education. Malaysia followed with 17%, reflecting its commitment to adopting AR technology to improve the vocational learning experience. Germany and China also made sizable contributions, with weights of 12% and 9%, respectively; these results indicate their investment in AR as a critical medium in facilitating technical training and development in the industrial world.

The remaining countries in Figure 9, including Spain and the United Kingdom, contribute 7% each. In comparison, the United States is responsible for 6% of AR applications in vocational education. Taiwan and Turkey contribute 5%, and Thailand has the smallest visible share at 4%. Overall, the distribution of contributing countries highlights the global interest in leveraging AR technology to advance vocational education, with countries recognizing the potential of AR to provide immersive and interactive learning environments that can significantly improve skills development and training.

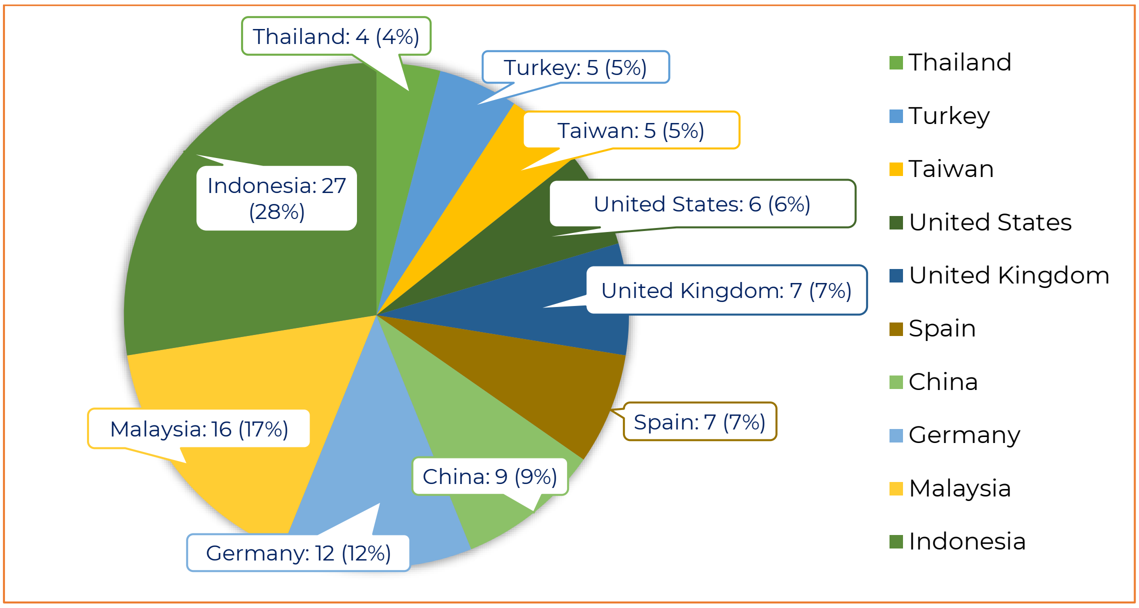

Figure 9. Top 10 countries most published on augmented reality in vocational education

In Figure 10, an infographic depicts the lines of influence of various publication sources on the quality of augmented reality publications in vocational education from 2016 to 2024. The "ACM International Conference Proceeding Series" peaked around 2018, showing a significant impact. The "Journal of Physics Conference Series" shows two peaks, one around 2017 and another in 2021, indicating a period of high influence. The "Lecture Notes in Computer Science" series, including sub-series in Artificial Intelligence and Bioinformatics, seems to have a declining influence over the years.

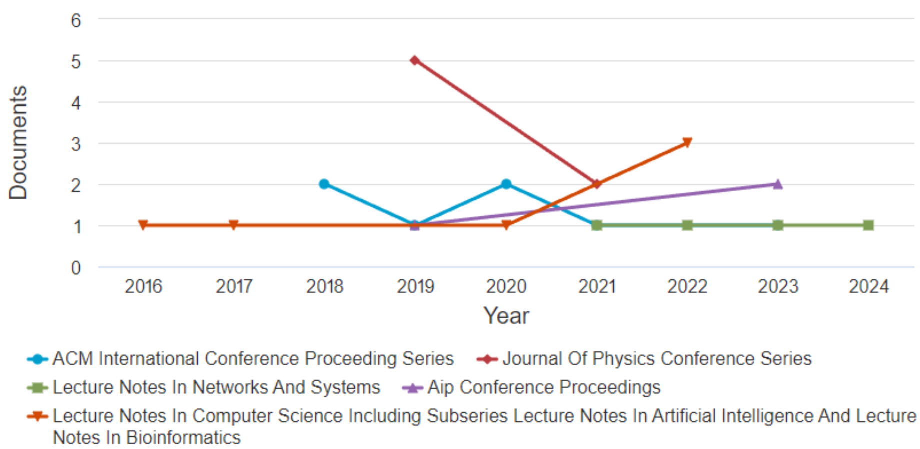

Figure 10. Top five sources of publications on AR in vocational education

In contrast, "Lecture Notes in Networks and Systems" maintained a stable presence, indicating consistent contributions to the field. Finally, "AIP Conference Proceedings" fluctuated slightly but showed no clear trend, implying a moderate and variable impact on the quality of AR publications in vocational education. Overall, these sources reflect the dynamic nature of research dissemination and the ever-evolving landscape of AR in vocational education.

As for the countries contributing to the utilization of VR technology in vocational education visualized through pie charts, Figure 11 provides a visual representation. The most significant contributor is China, which accounts for 39% of VR implementation in this sector, highlighting China's leading role in developing and integrating VR technology in vocational training and education. Followed by the United States, with a contribution of 8%; meanwhile, Germany is behind with 7%. Both countries are known for their technological advancements. They are proven to implement VR, especially using Oculus Rift devices to enhance the vocational learning experience.

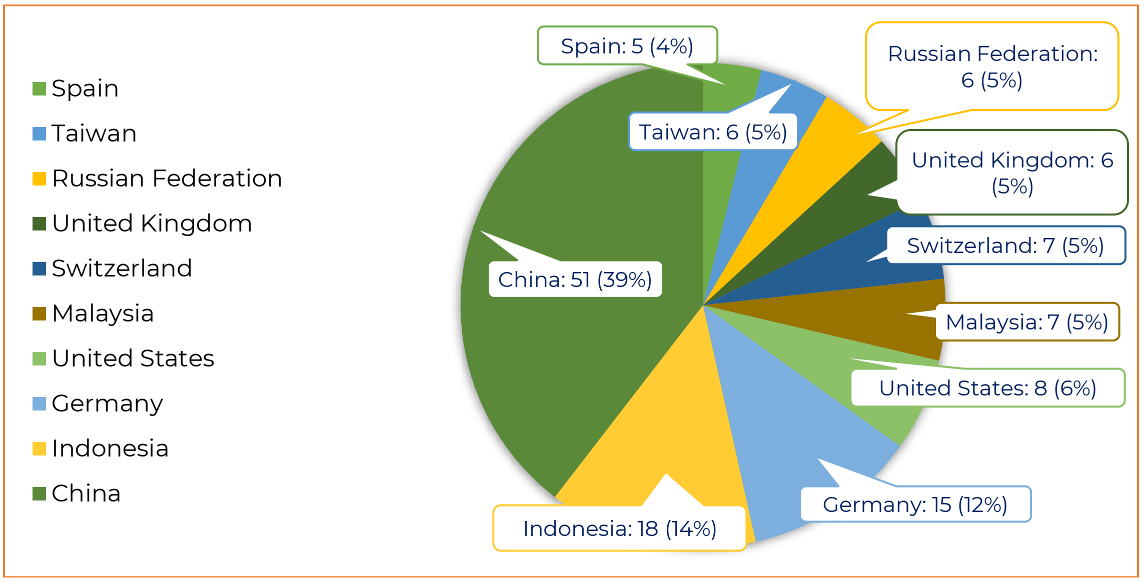

Figure 11. Top ten countries most publication on virtual reality in vocational education

Furthermore, followed Switzerland and Malaysia, each contributing 5%, showing active involvement in utilizing VR for sustainable education. The UK and the Russian Federation scored 6% each, while Spain also contributed 5%. Meanwhile, Indonesia stands out with a 14% contribution, strongly focusing on adopting VR technology in its vocational education system. Therefore, the contributions made by these ten countries reflect the global interest in utilizing VR technology to advance vocational education, with countries recognizing the potential of VR to provide immersive and interactive learning environments that can significantly enhance the development of practical skills in training.

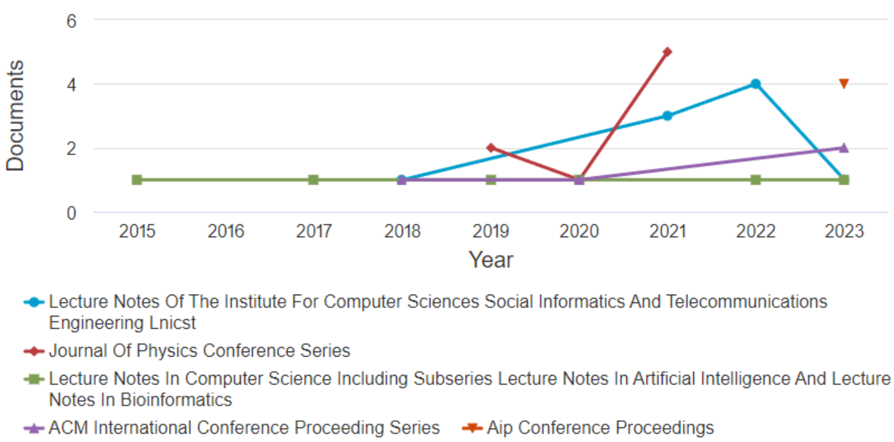

Figure 12. Top five sources of publications on VR in vocational education

Figure 12 presents a line graph illustrating the influence of various publication sources on the quality of publications using virtual reality in vocational education from 2015 to 2023. "Lecture Notes Of The Institute For Computer Sciences Social Informatics And Telecommunications Engineering LNCS" shows a consistent presence over the years, indicating a steady contribution to VR research. The "Journal of Physics Conference Series" has peaks indicating periods of significant impact, particularly around 2017 and 2021. The "Lecture Notes In Computer Science" series, including sub-series in Artificial Intelligence and Bioinformatics, seems to have a declining influence over the years. The "ACM International Conference Proceeding Series" peaked around 2018, signaling a solid impact. Eventually, "AIP Conference Proceedings" shows slight fluctuations but no clear trend, implying moderate and variable effects on the quality of VR publications in vocational education. Therefore, these sources have diverse and dynamic properties of research dissemination, especially in the evolving landscape of VR in vocational education.

Top 10 most cited authors' publications

RQ3. Who are the top 10 prolific authors contributing to research on AR and VR in vocational education?

Table 2 presents detailed information regarding the authors' most cited documents on Augmented Reality in vocational education, starting with the top research paper publication by (Bacca et al., 2015), published in Procedia Computer Science by Elsevier. This research paper has 104 citations according to Scopus and 140 according to Google Scholar, showing its relevant influence in the field of vocational education. The same research document published by the authors (Bacca et al., 2018, 2019) shows a high number of citations, with an affirmation of consistency as the first author who can produce research that has an impact until it is noticed by many researchers at the international level.

Table 2. Top ten most cited authors' documents on AR in vocational education

Author references	Region	Journal & Publisher	Cited by Scopus	Scholar citation
(Bacca et al., 2015)	Spain	Procedia Computer Science (Elsevier)	104	140
(Bacca et al., 2019)	Spain	Australasian Journal of Educational Technology	68	127
(Sirakaya & Cakmak, 2018)	Turkey	International Journal for Research in Vocational Education and Training	58	106
(Bacca et al., 2018)	Spain	Frontiers in Psycology	45	59
(Lee & Hsu, 2021)	Taiwan	Sustainability (Switzerland) MDPI	18	20
(Lester & Hofmann, 2020)	United Kingdom	British Journal of Educational Technology (Willey Online Library)	17	27
(Zulfabli et al., 2019)	Malaysia	Applied Physics of Condensed Matter (AIP Conference)	16	22
(Alptekin & Temmen, 2018)	Germany	IEEE Global Engineering Education Conference	15	21
(Putra et al., 2021)	Indonesia	International Journal of Interactive Mobile Technologies (iJIM)	13	23
(Pipattanasuk & Songsriwittaya, 2020)	Thailand	International Journal of Instruction	12	20

Furthermore, research by (Bacca et al., 2018, 2019) from Turkey, published in the International Journal for Research in Vocational Education and Training, also plays a crucial role with 58 Scopus citations and 106 citations according to Google Scholar. This data shows that their research is valued by both the scientific community and educational practitioners. Additionally, despite having fewer citations, publications by (Lee & Hsu, 2021) from Taiwan and (Lester & Hofmann, 2020) from the United Kingdom still made valuable contributions to the literature on AR utilization in vocational education. Meanwhile, studies from Malaysia, Germany, Indonesia, and Thailand are also included in this list, reflecting the global interest and application of AR in vocational education which, as a whole, Table 2 highlights the importance of AR in vocational education, especially towards the implementation and contribution of various researchers from around the world in advancing the field of vocational training and education.

Table 3 presents research data by calculating the highest number of citations about virtual reality in vocational education. Initially, the research findings by (Lerner et al., 2020), published in JMIR Serious Games, have garnered 43 citations on Scopus and 76 on Google Scholar. This outcome suggests their study has significantly impacted the scientific community and experts developing Virtual Reality technology for vocational education.

Table 3. Top ten most cited authors' documents on VR in vocational education

Author references	Region	Journal & Publisher	Cited by Scopus	Scholar citation
(Lerner et al., 2020)	Germany	JMIR Serious Games	43	76
(Babu et al., 2018)	India	IEEE 18th International Conference on Advanced Learning Technologies	40	64
(Smith et al., 2015)	United States	Journal of Vocational Rehabilitation	40	58
(Kim et al., 2020)	Switzerland	British Journal of Educational Technology (Willey Online Library)	31	58
(Sang et al., 2016)	China	International Journal of Distance Education Technologies	24	31
(Jantjies et al., 2018)	South Africa	ACM International Conference Proceeding Series	22	70
(Pletz, 2021)	Germany	International Journal of Emerging Technologies in Learning	20	27
(Beh et al., 2022)	Malaysia	Engineering, Construction, and Architectural Management (Emerald Insight)	18	25
(Chen et al., 2018)	China	Eurasia Journal of Mathematics, Science and Technology Education	17	44
(Noble et al., 2022)	United States	International Journal of Educational Technology in Higher Education (Springer Open)	13	27

Afterward, according to (Babu et al., 2018) from India and (Smith et al., 2015) from the United States both have 40 Scopus citations, showing strong influence in advanced education technology and vocational rehabilitation. In contrast, the research results by (Kim et al., 2020) from

Switzerland are also crucial, with 31 Scopus citations and 58 Scholar citations confirming the importance of educational technology in VR. Then, other research results from various leading countries such as China, South Africa, Germany, Malaysia, and the United States are included in Table 3, reflecting the authors' global interest in implementing VR applications in vocational education. These findings provide important insights into how VR can improve access to learning and training in various vocational education contexts to be more interactive and innovative.

Overall, the findings of publications that utilize AR and VR technologies in vocational education play a fundamental role in developing and expanding this research in various scientific fields. In particular, computer science, social science, engineering, and education contribute more to vocational education. Collaboration between researchers, educators, and industry can encourage innovation in using AR and VR in vocational education. This is an opportunity to develop learning materials more relevant to industry needs and open up opportunities for students to gain practical experience closer to real-world situations.

The findings can also serve as a foundation for further research that focuses on optimizing the use of these technologies in various educational environments. Consequently, the research that has been conducted by the authors in Tables 2 and 3 is consistently able to provide valuable insights into the utilization of AR and VR in vocational education can create an adaptive and effective learning ecosystem, which ultimately contributes to the advancement of educational technology and provides benefits to society at large.

Research gap and challenges of AR and VR in vocational education

RQ4. *What are the main gaps and challenges identified through the main keywords in using AR and VR in vocational education?*

Figure 13 presents a visualization in the form of a keyword cloud that prominently features "Vocational Education" and "Virtual Reality," highlighting the significant focus on integrating immersive technologies into theoretical and practical learning environments.

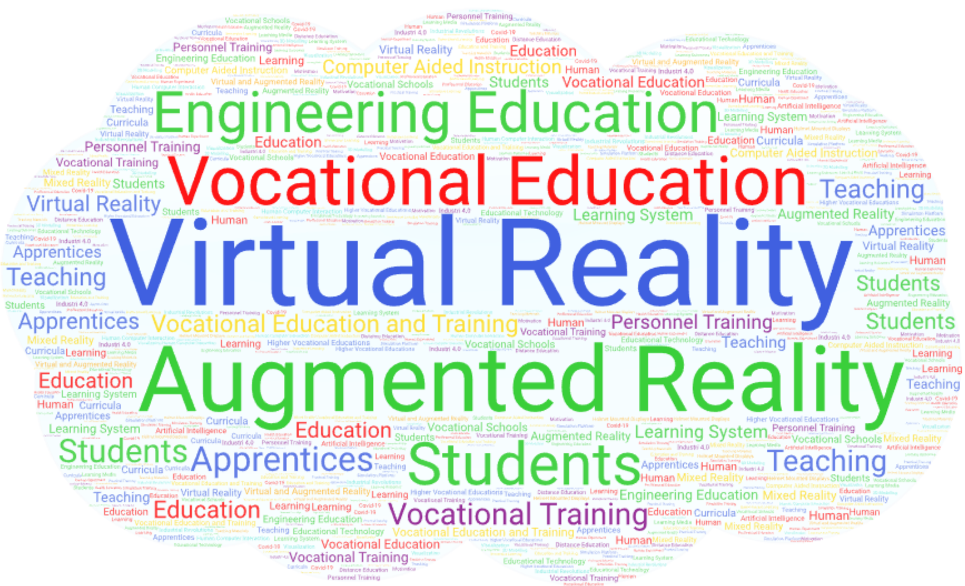

Figure 13. Visualization of keyword cloud on AR and VR in vocational education

The repeated occurrence of "Students," "Teaching," and "Training" underscores the educational context, where vocational training is adapting to include advanced tools such as virtual reality to enhance the learning experience. Terms such as "Engineering" and "Apprenticeship" indicate specific areas within vocational education that are most likely to benefit from these technological advancements. The inclusion of "Augmented Reality" demonstrates that alongside Virtual Reality, there is also interest in overlaying digital information onto the real world to enrich vocational training. Hence, the presentation of these keywords effectively captures the essence of modern educational trends, where technology plays a vital role in shaping how teachers and learners teach and learn vocational skills.

Figure 14 visualizes the network created with VOSviewer, a commonly used bibliometric analysis and visualization tool. The nodes in the network represent various concepts related to education and technology, such as "augmented reality," "virtual reality," "vocational education," "technical education," and "students." These nodes are interconnected, showing the interconnectedness related to the co-occurrence of these keywords.

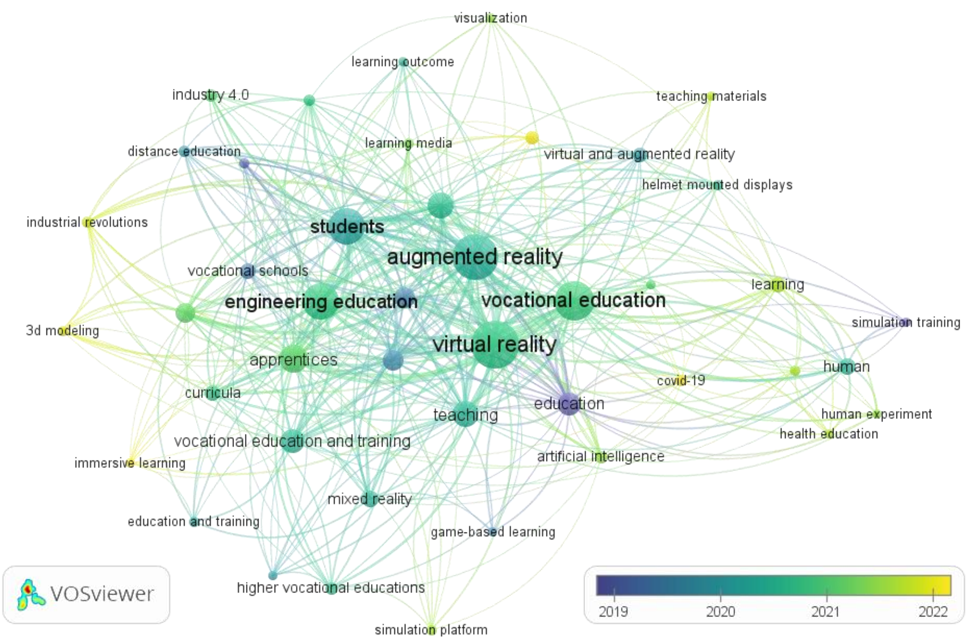

Figure 14. Visualization of author keywords from 2015 to 2024 in vocational education

Further interpretation of Figure 14 is found in the color gradient from dark blue to yellow, showing the timeline from 2019 to 2022. Darker colors, such as dark blue, represent earlier years. In comparison, lighter colors, such as yellow, are keywords that have emerged from more recent years. This data shows that the prominence or frequency of these terms and their relationships have been mapped out over the years. For example, "augmented reality" and "virtual vocational education," closer to the yellow part of the gradient, may have become more prominent or relevant in recent years, perhaps due to the increased focus on digital transformation and distance learning accelerated by the COVID-19 pandemic.

Meanwhile, key terms such as "student" and "technical education" are depicted with larger nodes, indicating that crucial concepts appear frequently or have essential meanings in the data set. The visualization also includes terms such as "3D modeling", "curriculum," "vocational training," and "artificial intelligence," which are connected to a central node, indicating the interdisciplinary nature of this research and the relationship between education and technology.

Overall, the visualization provided by Figure 14 provides a graphical representation of the evolution and relationship of various terms in education and technology, highlighting the main trends and focus areas from 2019 to 2022.

Based on the interpretation of keywords in the form of clouds and networks in Figures 13 and 14, overall, there are certainly gaps and challenges in vocational education, especially in terms of curriculum alignment with industry needs and evolving technologies. The keyword cloud in Figure 13 shows some exciting keywords such as "Training," "Vocational Education," and AR/VR technology, which continues to evolve into the main focus in preparing practically skilled students who understand how to implement the latest technology. However, the network in Figure 14 reveals research gaps that occur each year from 2019 to 2022 and has a connection between the concepts taught based on the world of work that changes yearly.

On the one hand, the main challenge from this bibliometric analysis is the need for rapid adaptation for vocational education curriculum developers to follow the trend of scientific and technological developments to be at the forefront. Some critical coverage of increased flexibility in learning methodologies and continuous updating of educational materials, especially in information technology, engineering, and vocational education, must be ready to anticipate future trends by prioritizing student needs and equipping students with relevant skills.

Additionally, the interpretation of the keyword distribution network shows that the collaboration between vocational education institutions and industry still needs to be improved, especially in curriculum adjustment and internship programs. Moreover, the emergence of an independent internship program from the Indonesian Ministry of Education is an opportunity to increase students' accessibility to their field experience by directly implementing the knowledge they have gained (Farida et al., 2022; Harmanto et al., 2022). Altogether, the cloud and network interpretations highlight the importance of innovation in vocational education to address the gap between education and workplace needs. Addressing this challenge will lead to more collaboration between educators, policymakers, and industry to ensure that vocational education remains relevant, interactive, and practical in the face of changes in the world of work.

Strength and opportunities of AR and VR in vocational education

RQ5. How do AR and VR technologies' strengths and opportunities impact vocational training and learning?

In addressing the research questions concerning the strengths and opportunities presented by augmented reality (AR) and virtual reality (VR) technologies in vocational education, intriguing findings emerged regarding the benefits derived from the implementation of AR in vocational training. One of these strengths is enhancing student motivation (Bacca et al., 2015, 2019). Conversely, studies highlighting the strengths and opportunities in the context of multi-user VR simulation training have the power to demonstrate the experience of presence and indirectly influence the cognitive learning process, resulting in better learning outcomes for students (Lerner et al., 2020). Additionally, the main strengths of AR and VR, in general, are creating. For example, AR technology can visually overlay real-time information against actual equipment or objects and develop students' insight, understanding, and retention of the information acquired (Oke & Arowoiya, 2022; Syed et al., 2023). Meanwhile, VR technology immersively allows students to engage in complex simulations, such as machine operations or complicated practical tasks, without the risk of accidents and equipment damage (Valentine et al., 2021).

Nonetheless, the accessibility offered by AR and VR technologies has a wide range of opportunities to increase access to high-quality education and training without geographical limitations (Garlinska et al., 2023). Notably, learners from remote locations can access the same training modules available in leading urban training centers. In addition, AR and VR enable personalization of learning, where training content can be tailored to meet individual learning needs, accelerating the learning curve and increasing learner motivation (Huang et al., 2023). Furthermore, AR and VR technologies provide opportunities to integrate real-time feedback in the learning process, meaning learners can receive immediate feedback on their actions and decisions in training sessions (Lee & Hsu, 2021). This opportunity will help correct mistakes quickly and reinforce learning through repetition and immediate correction.

The use of AR and VR in vocational training also enhances collaboration and communication between learners, regardless of their physical location (Pidel & Ackermann, 2020). With this technology, learners can collaborate in a virtual environment, collaborate on projects and tasks, and even carry out simulated group work. These interactions are invaluable in developing social and teamwork skills essential in many industry sectors. In addition, adopting AR and VR in vocational education allows educational institutions to reduce operational costs (Noghabaei et al., 2020). Virtual simulations lessen the need for expensive physical materials and equipment. They could reduce the risk of accidents, saving on insurance and maintenance costs (Javaid et al., 2023).

Ultimately, the widespread use of these technologies optimizes the learning process and helps prepare learners to adapt to future technologies. Notably, in the world of work increasingly relying on advanced technology, having expertise in virtual and augmented technology makes this a precious asset in adding value to the professionalism of learners. Consequently, through the advanced simulation process and the rich learning experience of visuals and simulations, learners are expected to develop skills relevant to the current and future job market, thus preparing them better for the challenges of modern industry.

4. Conclusion

This bibliometric analysis research thoroughly explores the trends and developments in utilizing Augmented Reality (AR) and Virtual Reality (VR) in vocational education over the past decade, from 2015 to 2024. The findings obtained in this bibliometric analysis research are firstly related to the distribution of the top publications, which reveals the importance of AR and VR publications that are widely used in Interdisciplinary sectors that include not only technologies in the fields of Computer Science or Engineering but also essential sectors of Social Sciences, which indicates the need for relevance in any Vocational Education intervention (Baccassino & Pinnelli, 2023; Pinnegar & Cutri, 2022). Regardless of the relatively broad distribution trends of AR and VR technologies, the use of VR seems to be more dominant in the number of publications and broader scientific fields. Conversely, AR tends to have a relatively higher average of citations per publication.

Subsequently, the publication trend shows a significant increase starting from 2015, peaking in 2021-2022, especially for AR and VR. The distribution of the most contributing countries also highlights the global interest in utilizing these technologies, especially countries such as China, Germany, and the United States, which are the countries with the most significant contributions in VR publications, while Malaysia and Indonesia have significant contributions in AR publications. In addition, the findings of this study identified the top 10 most contributing authors with the top number of citations on the utilization of AR and VR in vocational education. These authors come from countries such as Spain, the United States, Germany, and India, which play fundamental roles in developing and expanding this research.

Meanwhile, AR and VR technologies have much vocational potential, but some gaps and challenges exist. Key challenges include curriculum alignment with industry needs and rapid adaptation to technological developments. On the other hand, gaps in collaboration between vocational education institutions and industry must also be improved to address the evolving training needs of the future. In addition, these technologies can create realistic and interactive learning environments by immersively visualizing the experience and accelerating the learning curve. In addition, AR and VR have exciting opportunities, significantly escalated access to education without geographical restrictions, personalization of learning, and integration of real-time feedback in the learning process.

In conclusion, this study highlights the great potential of AR and VR in improving vocational education. It identifies the need for further research, collaboration between researchers, educators, and industry, and curriculum development responsive to emerging technologies. By strategically leveraging augmented reality (AR) and virtual reality (VR), vocational education can become more adaptable to future requirements. In equipping students with the skills necessary to navigate technological transformations and seamlessly transition into the industrial sector, fostering attributes like integrity, teamwork, collaboration, and strong decision-making abilities is crucial.

Implications and recommendations

This research suggests that vocational education institutions and policymakers consider AR and VR effective and innovative learning tools. Increasing collaboration between educational institutions and industry will be essential in addressing the gaps and challenges identified in this research. Efforts to address these challenges will result in better quality vocational education and benefit society. Above all else, this technology enables collaboration and communication between learners regardless of their physical location, encouraging cooperation and interaction in group-based learning projects.

Future research must focus more on the implementation and evaluation of the use of AR and VR technologies in vocational education. Moreover, it is essential to broaden the scope of bibliometric analysis by including databases like Web of Science, DOAJ, EBSCO, and PubMed to identify effective strategies that can ensure the sustainable positive impact of these technologies in the educational domain. Additionally, government stakeholders should reconsider traditional learning methods, aiming to incorporate AR and VR technologies at a reduced cost. This initiative can support vocational schools and educational institutions in accessing updated and renewable learning approaches at more affordable rates.

Author contribution

Aprilla Fortuna: Writing – review & editing, Writing – original draft, Visualization, Sofware, Conceptualization, Data curation, Project administration. Febri Prasetya: Writing – original draft, Writing – review & editing, Methodology, Formal analysis, Supervision. Amna Salman: Writing – review & editing, Formal analysis, Software, Validation. Amir Karimi: Writing – review & editing, Methodology, Data curation, Validation. Juana Maria Arcelus-Ulibarrena: Writing – review & editing, Formal analysis, Software, Visualization. Juan Luis Cabanillas García: Writing – review & editing, Visualization, Conceptualization Methodology. Ahmad Yusuf: Data curation, Visualization, Resources.

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Conflict of interest

There are no competing interests for all authors.

References

Ahmad, T. (2020). Scenario based approach to re-imagining future of higher education which prepares students for the future of work. *Higher Education, Skills and Work-Based Learning*, *10*(1), 217–238. https://doi.org/10.1108/HESWBL-12-2018-0136

Alalwan, N., Cheng, L., Al-Samarraie, H., Yousef, R., Ibrahim Alzahrani, A., & Sarsam, S. M. (2020). Challenges and Prospects of Virtual Reality and Augmented Reality Utilization among Primary School Teachers: A Developing Country Perspective. *Studies in Educational Evaluation*, *66*, 100876. https://doi.org/10.1016/j.stueduc.2020.100876

AlGerafi, M. A. M., Zhou, Y., Oubibi, M., & Wijaya, T. T. (2023). Unlocking the Potential: A Comprehensive Evaluation of Augmented Reality and Virtual Reality in Education. *Electronics (Switzerland)*, *12*(18), 1–29. https://doi.org/10.3390/electronics12183953

Alptekin, M., & Temmen, K. (2018). Design Concept and Prototype for an Augmented Reality based virtual preparation laboratory training in Electrical Engineering Mesut. *IEEE Global Engineering Education Conference*, 963–968. https://doi.org/10.1109/EDUCON.2018.8363334

Babu, S. K., Krishna, S., Unnikrishnan, R., & Bhavani, R. R. (2018). Virtual reality learning environments for vocational education : A comparison study with conventional instructional media on knowledge retention . *IEEE 18th International Conference on Advanced Learning Technologies*, 385–389. https://doi.org/10.1109/ICALT.2018.00094

Bacca, J., Baldiris, S., Fabregat, R., & Kinshuk. (2018). Insights into the factors influencing student motivation in Augmented Reality learning experiences in Vocational Education and Training. *Frontiers in Psychology*, *9*, 1–13. https://doi.org/10.3389/fpsyg.2018.01486

Bacca, J., Baldiris, S., Fabregat, R., & Kinshuk. (2019). Framework for designing motivational augmented reality applications in vocational education and training. *Australasian Journal of Educational Technology*, *35*(3), 102–117. https://doi.org/10.14742/ajet.4182

Bacca, J., Baldiris, S., Fabregat, R., Kinshuk, & Graf, S. (2015). Mobile Augmented Reality in Vocational Education and Training. *Procedia Computer Science*, *75*, 49–58. https://doi.org/10.1016/j.procs.2015.12.203

Baccassino, F., & Pinnelli, S. (2023). Giftedness and gifted education: A systematic literature review. *Frontiers in Education*, 7, 1–18. https://doi.org/10.3389/feduc.2022.1073007

Beh, H. J., Rashidi, A., Talei, A., & Lee, Y. S. (2022). Developing engineering students' capabilities through game-based virtual reality technology for building utility inspection.

Engineering, Construction and Architectural Management, *29*(7), 2854–2877. https://doi.org/10.1108/ECAM-02-2021-0174

Chen, Y. F., Luo, Y. Z., Fang, X., & Shieh, C. J. (2018). Effects of the application of computer multimedia teaching to automobile vocational education on students' learning satisfaction and learning outcome. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(7), 3293–3300. https://doi.org/10.29333/ejmste/91245

Childs, E., Mohammad, F., Stevens, L., Burbelo, H., Awoke, A., Rewkowski, N., & Manocha, D. (2023). An Overview of Enhancing Distance Learning Through Emerging Augmented and Virtual Reality Technologies. *IEEE Transactions on Visualization and Computer Graphics*, 1–15. https://doi.org/10.1109/TVCG.2023.3264577

Criollo-c, S., Guerrero-arias, A., Guaña-moya, J., Samala, A. D., & Luj, S. (2024). Towards Sustainable Education with the Use of Mobile Augmented Reality in Early Childhood and Primary Education : A Systematic Mapping. *Sustainability (Switzerland)*, *16*, 1–14. https://doi.org/10.3390/su16031192

Farida, I., Ardiansyah, M., Juwita, M. N., Rinova, D., & Soewito, S. (2022). Implementation of Internship Program as A Form of MBKM Learning Activities in Improving Students' Competency. *Nusantara: Jurnal Pendidikan Indonesia*, *2*(1), 107–122. https://doi.org/10.14421/njpi.2022.v2i1-7

Fortuna, A., Waskito, W., Purwantono, P., Kurniawan, A., Andriani, W., & Alimin, M. (2023). Designing Learning Media Using Augmented Reality for Engineering Mechanics Course. *Journal of Engineering Researcher and Lecturer*, *2*(1), 18–27. https://doi.org/https://doi.org/10.58712/jerel.v2i1.20

Gajdzik, B., & Wolniak, R. (2022). Smart Production Workers in Terms of Creativity and Innovation: The Implication for Open Innovation. *Journal of Open Innovation: Technology, Market, and Complexity*, *8*(2), 1–32. https://doi.org/10.3390/joitmc8020068

Garlinska, M., Osial, M., Proniewska, K., & Pregowska, A. (2023). The Influence of Emerging Technologies on Distance Education. *Electronics (Switzerland)*, *12*(7), 1–29. https://doi.org/10.3390/electronics12071550

Guray, T. S., & Kismet, B. (2023). VR and AR in construction management research: bibliometric and descriptive analyses. *Smart and Sustainable Built Environment*, *12*(3), 635–659. https://doi.org/10.1108/SASBE-01-2022-0015

Harmanto, H., Yulianto, B., Sholeh, M., Subekti, H., & Sueb, S. (2022). Strategies to Implement Independent Learning Programs: A Reflective Study on Ministerial Programs. *Proceedings of the Eighth Southeast Asia Design Research (SEA-DR) & the Second Science, Technology, Education, Arts, Culture, and Humanity (STEACH) International Conference*, *627*, 346–352. https://doi.org/10.2991/assehr.k.211229.054

Huang, A. Y. Q., Lu, O. H. T., & Yang, S. J. H. (2023). Effects of artificial Intelligence–Enabled personalized recommendations on learners' learning engagement, motivation, and outcomes in a flipped classroom. *Computers and Education*, *194*(June 2022), 104684. https://doi.org/10.1016/j.compedu.2022.104684

Jantjies, M., Moodley, T., & Maart, R. (2018). Experiential learning through virtual and augmented reality in higher education. *ACM International Conference Proceeding Series*, 42–45. https://doi.org/10.1145/3300942.3300956

Javaid, M., Haleem, A., & Suman, R. (2023). Digital Twin applications toward Industry 4.0: A Review. *Cognitive Robotics*, *3*, 71–92. https://doi.org/10.1016/j.cogr.2023.04.003

Kim, K. G., Oertel, C., Dobricki, M., Olsen, J. K., Coppi, A. E., Cattaneo, A., & Dillenbourg, P. (2020). Using immersive virtual reality to support designing skills in vocational education. *British Journal of Educational Technology*, *51*(6), 2199–2213. https://doi.org/10.1111/bjet.13026

Lee, C. J., & Hsu, Y. (2021). Sustainable education using augmented reality in vocational certification courses. *Sustainability (Switzerland)*, *13*(11), 1–15. https://doi.org/10.3390/su13116434

Lerner, D., Mohr, S., Schild, J., Martin, G., & Luiz, T. (2020). An Immersive Multi-User Virtual Reality for Emergency Simulation Training: Usability Study. *JMIR Serious Games*, *8*(3), 1–10. https://doi.org/10.2196/18822

Lester, S., & Hofmann, J. (2020). Some pedagogical observations on using augmented reality in a vocational practicum. *British Journal of Educational Technology*, *51*(3), 645–656. https://doi.org/10.1111/bjet.12901

Majid, M. Z. A., Kasavan, S., & Siron, R. (2024). Bibliometric analysis and science mapping of global scientific publications on technical vocational education training (TVET). *Library Hi Tech*, *42*(1), 8–32. https://doi.org/10.1108/LHT-12-2021-0485

McAllister, J. T., Lennertz, L., & Atencio Mojica, Z. (2022). Mapping A Discipline: A Guide to Using VOSviewer for Bibliometric and Visual Analysis. *Science and Technology Libraries*, *41*(3), 319–348. https://doi.org/10.1080/0194262X.2021.1991547

Mhlongo, S., Mbatha, K., Ramatsetse, B., & Dlamini, R. (2023). Challenges, opportunities, and prospects of adopting and using smart digital technologies in learning environments: An iterative review. *Heliyon*, *9*(6), e16348. https://doi.org/10.1016/j.heliyon.2023.e16348

Noble, S. M., Saville, J. D., & Foster, L. L. (2022). VR as a choice: what drives learners' technology acceptance? *International Journal of Educational Technology in Higher Education*, *19*(1), 1–21. https://doi.org/10.1186/s41239-021-00310-w

Noghabaei, M., Heydarian, A., Balali, V., & Han, K. (2020). Trend analysis on adoption of virtual and augmented reality in the architecture, engineering, and construction industry. *Data*, *5*(1), 1–18. https://doi.org/10.3390/data5010026

Oke, A. E., & Arowoiya, V. A. (2022). An analysis of the application areas of augmented reality technology in the construction industry. *Smart and Sustainable Built Environment*, *11*(4), 1081–1098. https://doi.org/10.1108/SASBE-11-2020-0162

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *The BMJ*, *372*. https://doi.org/10.1136/bmj.n71

Pellas, N., Mystakidis, S., & Kazanidis, I. (2021). Immersive Virtual Reality in K-12 and Higher Education: A systematic review of the last decade scientific literature. *Virtual Reality*, *25*(3), 835–861. https://doi.org/10.1007/s10055-020-00489-9

Pidel, C., & Ackermann, P. (2020). Collaboration in Virtual and Augmented Reality: A Systematic Overview. *Augmented Reality, Virtual Reality, and Computer Graphics*, 141–156. https://doi.org/10.1007/978-3-030-58465-8_10

Pinnegar, S., & Cutri, R. M. (2022). Insights in teacher education. In *Frontiers in Education* (pp. 1–161). https://doi.org/10.3389/978-2-8325-4831-8

Pipattanasuk, T., & Songsriwittaya, A. (2020). Development of an instructional model with augmented reality technology for vocational certificate students. *International Journal of Instruction*, *13*(3), 539–554. https://doi.org/10.29333/iji.2020.13337a

Pletz, C. (2021). Which Factors Promote and Inhibit the Technology Acceptance of Immersive Virtual Reality Technology in Teaching-Learning Contexts? Results of an Expert Survey. *International Journal of Emerging Technologies in Learning (IJET)*, *16*(13), 248–272. https://doi.org/10.3991/ijet.v16i13.20521

Prasetya, F., Fajri, B. R., Wulansari, R. E., Primawati, P., & Fortuna, A. (2023). Virtual Reality Adventures as an Effort to Improve the Quality of Welding Technology Learning During a Pandemic. *International Journal of Online and Biomedical Engineering*, *19*(2), 4–22.

Prasetya, F., Fortuna, A., Samala, A. D., Fajri, B. R., Efendi, F., & Nyamapfene, A. (2023). Effectiveness of Distance Learning Computer Numerical Control Based on Virtual Laboratory Using a Metaverse Platform to Improve Students' Cognitive Ability and Practice Skills. *International Journal of Interactive Mobile Technologies (IJIM)*, *17*(24), 4–21. https://doi.org/10.3991/ijim.v17i24.45019

Prasetya, F., Fortuna, A., Samala, A. D., Rawas, S., Mystakidis, S., Syahril, Waskito, Primawati, Wulansari, R. E., & Kassymova, G. K. (2024). The impact of augmented reality learning experiences based on the motivational design model: A meta-analysis. *Social Sciences & Humanities Open*, *10*(April), 100926. https://doi.org/10.1016/j.ssaho.2024.100926

Putra, A. B. N. R., Mukhadis, A., Ulfatin, N., Tuwoso, Subandi, M. S., Hardika, & Muhammad, A. K. (2021). The Innovation of Disruptive Learning Media with Augmented Reality Based 3D Object Concept with Drill Machine Design to Improve Quality of Distance Learning in The Era of Education 4.0. *International Journal of Interactive Mobile Technologies (IJIM)*, *15*(12), 193–200. https://doi.org/10.3991/ijim.v15i12.21579

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers and Education*, *147*, 103778. https://doi.org/10.1016/j.compedu.2019.103778

Raji, B. (2019). Significance and challenges of computer assisted education programs in the UAE: A case study of higher learning and vocational education. *Education and Information Technologies*, *24*(1), 153–164. https://doi.org/10.1007/s10639-018-9767-6

Refdinal, R., Adri, J., Prasetya, F., Tasrif, E., & Anwar, M. (2023). Effectiveness of Using Virtual Reality Media for Students' Knowledge and Practice Skills in Practical Learning. *JOIV: International Journal on Informatics Visualization*, 7(3), 688–694. https://doi.org/10.30630/joiv.7.3.2060

Remolar, I., Rebollo, C., & Fernández-Moyano, J. A. (2021). Learning history using virtual and augmented reality. *Computers*, *10*(11), 1–19. https://doi.org/10.3390/computers10110146

Samala, A. D., Govender, T., Tsoy, D., Bojic, L., Samala, A. G., Samala, M. P., Prasetya, F., Tri, D., Yanto, P., Zainul, R., & Fortuna, A. (2024). 3D Visualizations in Learning : An Evaluation of an AR + Core Application for Computer Hardware Education using the Hedonic Motivation System Adoption Model. *TEM Journal*, *13*(1), 466–475. https://doi.org/10.18421/TEM131-48

Samala, A. D., Usmeldi, U., Taali, T., Daineko, Y., Indarta, Y., Nando, Y. A., Anwar, M., Jaya, P., & Almasri, A. (2023). Global Publication Trends in Augmented Reality and Virtual Reality for Learning: The Last Twenty-One Years. *International Journal of Engineering Pedagogy (IJEP)*, *13*(2), 109–128. https://doi.org/10.3991/ijep.v13i2.35965

Sang, Y., Zhu, Y., Zhao, H., & Tang, M. (2016). Study on an interactive truck crane simulation platform based on virtual reality technology. *International Journal of Distance Education Technologies*, *14*(2), 64–78. https://doi.org/10.4018/IJDET.2016040105

Scheid, R. (2018). Learning factories in vocational schools: Challenges for designing and implementing learning factories at vocational schools. In *Digital Workplace Learning: Bridging Formal and Informal Learning with Digital Technologies* (pp. 271–289). https://doi.org/10.1007/978-3-319-46215-8_15

Sima, V., Gheorghe, I. G., Subić, J., & Nancu, D. (2020). Influences of the industry 4.0 revolution on the human capital development and consumer behavior: A systematic review. *Sustainability (Switzerland)*, *12*(10), 1–28. https://doi.org/10.3390/su12104035

Sirakaya, M., & Cakmak, E. K. (2018). Effects of augmented reality on student achievement and self-efficacy in vocational education and training. *International Journal for Research in Vocational Education and Training*, *5*(1), 1–18. https://doi.org/10.13152/IJRVET.5.1.1

Smith, M. J., Boteler Humm, L., Fleming, M. F., Jordan, N., Wright, M. A., Ginger, E. J., Wright, K., Olsen, D., & Bell, M. D. (2015). Virtual reality job interview training for veterans with posttraumatic stress disorder. *Journal of Vocational Rehabilitation*, *42*(3), 271–279. https://doi.org/10.3233/JVR-150748

Soliman, M., Pesyridis, A., Dalaymani-Zad, D., Gronfula, M., & Kourmpetis, M. (2021). The application of virtual reality in engineering education. *Applied Sciences (Switzerland)*, *11*(6), 1–14. https://doi.org/10.3390/app11062879

Spöttl, G., & Windelband, L. (2021). The 4th industrial revolution–its impact on vocational skills. *Journal of Education and Work*, *34*(1), 29–52. https://doi.org/10.1080/13639080.2020.1858230

Syed, T. A., Siddiqui, M. S., Abdullah, H. B., Jan, S., Namoun, A., Alzahrani, A., Nadeem, A., & Alkhodre, A. B. (2023). In-Depth Review of Augmented Reality: Tracking Technologies, Development Tools, AR Displays, Collaborative AR, and Security Concerns. *Sensors*, *23*(1), 1–54. https://doi.org/10.3390/s23010146

Timotheou, S., Miliou, O., Dimitriadis, Y., Sobrino, S. V., Giannoutsou, N., Cachia, R., Monés, A. M., & Ioannou, A. (2023). Impacts of digital technologies on education and factors influencing schools' digital capacity and transformation: A literature review. In *Education and Information Technologies* (Vol. 28, Issue 6). Springer US. https://doi.org/10.1007/s10639-022-11431-8

Valentine, A., der Veen, T. Van, Kenworthy, P., Hassan, G. M., Guzzomi, A., Khan, R. N., & Male, S. A. (2021). Using head mounted display virtual reality simulations in large engineering classes: Operating vs observing. *Australasian Journal of Educational Technology*, *37*(3), 119–136. https://doi.org/10.14742/ajet.5487

Waskito, Fortuna, A., Prasetya, F., Wulansari, R. E., Nabawi, R. A., & Luthfi, A. (2024). Integration of Mobile Augmented Reality Applications for Engineering Mechanics Learning with Interacting 3D Objects in Engineering Education. *International Journal of Information and Education Technology*, *14*(3), 354–361. https://doi.org/10.18178/ijiet.2024.14.3.2057

Xiong, J., Hsiang, E. L., He, Z., Zhan, T., & Wu, S. T. (2021). Augmented reality and virtual reality displays: emerging technologies and future perspectives. *Light: Science and Applications*, *10*(1), 1–30. https://doi.org/10.1038/s41377-021-00658-8

Zhang, Y., Liu, H., Kang, S. C., & Al-Hussein, M. (2020). Virtual reality applications for the built environment: Research trends and opportunities. *Automation in Construction*, *118*, 103311. https://doi.org/10.1016/j.autcon.2020.103311

Zulfabli, H. M., Ismalina, H. N., Amarul, T., & Ahmad, S. (2019). Product development of mechanical practice: Augmented reality (AR) approach. *Applied Physics of Condensed Matter*, *2131*, 020055. https://doi.org/10.1063/1.5118063