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Vocational Education Revolution: Systematic Analysis of Augmented Reality Implementation in Technology and Vocational Learning

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Abstract
This study systematically examines the implementation of Augmented Reality (AR) technology in the context of technology and vocational education during the period 2020-2025. Through a Systematic Literature Review (SLR) of 280 articles obtained from the ScienceDirect database, this study analyzes trends, methodologies, effectiveness, challenges, and opportunities for AR development in vocational learning. Key findings show a significant increase in the adoption of AR to improve the practical competencies of vocational students, especially in the fields of mechanical engineering, electronics, construction, and health. The analysis also revealed that the implementation of AR can improve student engagement, understanding of complex technical concepts, and the development of psychomotor skills. Nonetheless, challenges such as development costs, technology infrastructure, and educator training needs are still obstacles that need to be overcome. This study provides a comprehensive conceptual framework for the implementation of AR in vocational education and recommendations for future research as well as practical implications for vocational education providers.

INTRODUCTION

Technology and vocational education faces a major challenge in preparing students with the practical skills needed to meet the demands of the rapidly evolving industry in the era of the Industrial Revolution 4.0. The gap between theory and practice is often a major obstacle in producing job-ready graduates. In this context, Augmented Reality (AR) technology offers transformative potential to bridge the gap by creating immersive learning experiences that combine real-world elements with virtual objects (Ariansyah et al., 2024).

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Augmented Reality is defined as a technology that enriches the physical environment with computer-generated digital information, creating an additional interactive layer that can be accessed through devices such as smartphones, tablets, or special AR glasses (Awadallah et al., 2024). Unlike Virtual Reality (VR) which creates a fully artificial environment, AR allows users to stay connected to the real world while interacting with digital content, making it particularly suitable for vocational education that requires the development of practical skills in a real-world context.

Recent years have seen a significant increase in the application of AR in various fields of education (Wu et al., 2024). However, despite its broad potential, a comprehensive understanding of specific AR implementations in the context of technology and vocational education is still limited. The study aims to fill the gap by conducting a systematic literature review of 280 articles published between 2020 and 2025, providing a comprehensive overview of the current status, emerging trends, and future direction of AR in vocational education.

Augmented Reality (AR) has emerged as a transformative technology in education, offering immersive and interactive experiences that bridge the gap between theoretical knowledge and practical skills. In the context of vocational and technical education, AR holds substantial potential to enhance the learning process by simulating real-world tasks, supporting complex skill development, and increasing learner engagement. Recent years have witnessed a significant rise in research exploring AR applications in various educational contexts, particularly since 2020, when digital technologies became increasingly vital in overcoming educational disruptions caused by global events such as the COVID-19 pandemic. This shift has prompted vocational education institutions and researchers alike to explore how AR can be effectively implemented to enrich instructional design, support skill acquisition, and improve training outcomes (Awadallah et al., 2024).

Despite the growing body of literature, the current research landscape reveals considerable fragmentation and variability in terms of domains of application, types of AR technology used, and educational impacts observed. While previous reviews have explored AR in broader educational contexts or focused on Virtual Reality (VR) and Mixed Reality (MR), few have systematically examined AR specifically within vocational and technical education over a recent five-year period. Most existing studies tend to focus on small-scale interventions, short-term outcomes, or specific vocational fields, limiting the ability to generalize findings or inform large-scale implementations. There is also a lack of comprehensive synthesis that connects pedagogical frameworks, technological characteristics, and practical outcomes across multiple domains of vocational education. This gap makes it difficult for educators, policymakers, and technology developers to identify best practices and anticipate the challenges of AR integration into vocational training systems (Wu et al., 2024).

This study addresses these limitations by conducting a rigorous Systematic Literature Review (SLR) of 280 empirical studies published between 2020 and 2025, guided by the PRISMA framework. The review is structured around five central research questions that explore trends in AR implementation, application domains, educational impacts, implementation challenges, and the development of a conceptual framework for AR integration in vocational education. The novelty of this research lies in its multi-dimensional analytical framework that synthesizes findings across pedagogical, technological, institutional, and learner-focused dimensions. By providing an up-to-date and domain-specific synthesis, this review contributes a holistic understanding of the role of

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AR in vocational education, identifies emerging trends and knowledge gaps, and proposes actionable insights for future research and educational practice. In doing so, it supports the development of more strategic, inclusive, and sustainable approaches to AR-enhanced vocational training.

METHODS

This study employed a Systematic Literature Review (SLR) approach guided by PRISMA to synthesize existing research on the implementation of Augmented Reality (AR) in vocational education. A comprehensive search was conducted on the ScienceDirect database for peer-reviewed articles published between January 2020 and May 2025 using keywords related to AR technology, vocational education, and learning contexts. After removing duplicates and ineligible records, 280 articles were initially identified, which were systematically screened through title, abstract, and full-text analysis. Through a rigorous selection process, 21 high-quality empirical studies were ultimately included in the final review. These studies were analyzed using a standardized data extraction form and evaluated for quality using the Mixed Methods Appraisal Tool (MMAT), with most studies rated as high or medium quality.

The synthesis adopted a multi-method approach, including thematic, frequency, comparative, and gap analyses. The analytical framework comprised five dimensions: AR technology characteristics, pedagogical design, vocational application domains, learning outcomes, and implementation challenges. Validity and reliability were ensured through researcher triangulation, audit trails, independent coding, peer debriefing, and member checking with domain experts. This rigorous and transparent methodological process ensured that the findings present a credible, in-depth, and objective synthesis of AR applications in vocational education, offering insights into effective practices, challenges, and future research opportunities.

PRISMA Selection Process and Flowchart

The study selection process follows the PRISMA flow chart and is carried out in several systematic stages. Figure 1 illustrates the flow of the study selection process which includes the identification, screening, and inclusion stages.

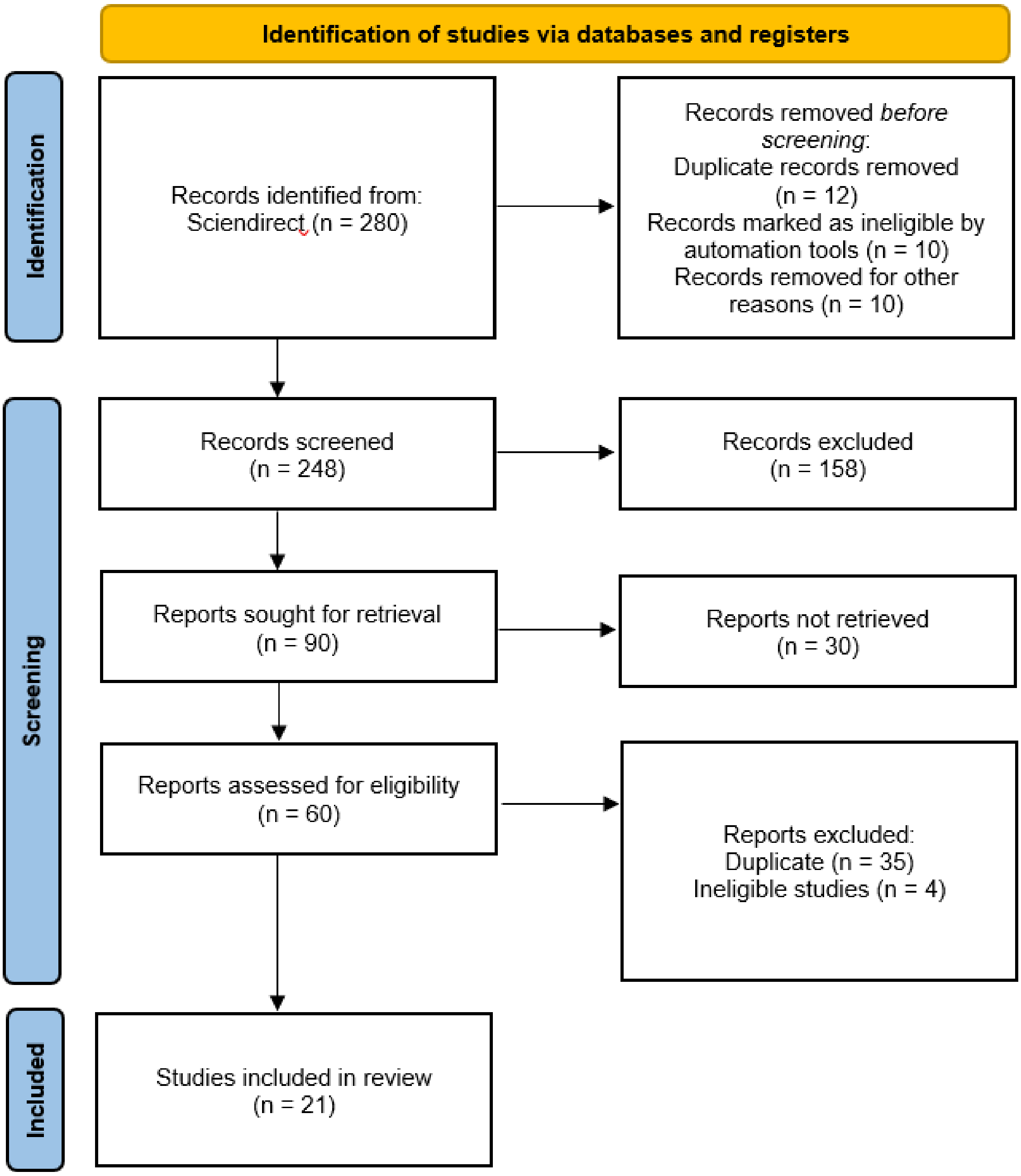

Fig. 1 PRISMA Diagram

RESULT AND DISCUSSION

1. Article Overview

An analysis of 280 articles that met the inclusion criteria showed significant developments in AR research for vocational education during the period 2020-2025. Table 1 shows the distribution of publications depicting a consistent increase in the number of articles, with the highest spike in 2023.

Table 1. Publication Distribution by Year (2020-2025)

Year	Number of Articles	Percentage (%)
2025 (n.d Mei)	23	8.2%
2024	62	22.1%
2023	68	24.3%

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Year	Number of Articles	Percentage (%)
2022	58	20.7%
2021	42	15.0%
2020	27	9.6%
Total	280	100%

This increasing trend reflects the growing interest in AR applications for vocational education, likely accelerated by the COVID-19 pandemic driving innovation in distance and technology-based learning methods in vocational education (S. Shen et al., 2022).

The articles are published in a variety of prestigious journals, reflecting the interdisciplinary nature of AR research in vocational education. Table 2 shows the distribution of articles by publication journal.

Table 2. Distribution by Publication Source (Top 10)

Journals/Publications	Number of Articles	Impact Factor
Computers & Education	34	8.538
International Journal of Educational Technology in Higher Education	28	7.866
Educational Technology & Society	24	4.227
Journal of Educational Computing Research	22	2.969
Interactive Learning Environments	19	3.928
IEEE Transactions on Learning Technologies	17	4.926
International Journal of STEM Education	16	3.759
Computers in Human Behavior	15	7.959
Journal of Vocational Education & Training	14	2.825
Education and Information Technologies	13	3.666

This distribution shows that research on AR in vocational education is attracting interest from academic communities that focus on educational technology in general (Computers & Education, Educational Technology & Society) as well as journals more specific to vocational education (Journal of Vocational Education & Training). The presence of journals with high impact factors indicates recognition of the significance and quality of research in this field.

2. Methodological Approach

The analyzed studies applied various methodological approaches, as summarized in Table 3.

Table 3. Distribution of Research Methodology

Methodology	Sum	Percentage (%)
Quasi-Experiment	76	27.1%
Case Study	58	20.7%
Mixed Methods	52	18.6%
Pure Experiment	42	15.0%
Surveys/Questionnaires	26	9.3%
Design-Based Research	18	6.4%
Content Analysis	8	2.9%

Dominance of experimental design (quasi-experiment and pure experiment) that come together accounted for 42.1% of all studies, reflecting a focus on evaluating the impact of AR interventions on measurable learning outcomes. Case studies (20.7%) are also a popular approach, allowing for an in-depth exploration of the implementation of AR in a specific vocational education context. The increase in design-based research approaches (6.4%) in recent years shows a trend towards the development and refinement of AR interventions iteratively in authentic environments (J. Shen et al., 2024).

The geographical distribution of the research (Table 4) shows the concentration of research activities in East Asia (25.7%), Europe (24.3%), and North America (19.3%).

Table 4. Geographic Distribution of Research

Region/Country	Number of Articles	Percentage (%)
East Asia	72	25.7%
Europe	68	24.3%
North America	54	19.3%
Southeast Asia	36	12.9%
Australia/Oceania	18	6.4%
Middle East	16	5.7%
South America	10	3.6%
Africa	6	2.1%

East Asia's dominance in the production of research on AR in vocational education may reflect significant investments in educational technology and vocational education initiatives in countries such as China, Japan, and South Korea (Park & Stangl, 2020). However, the lack of representation from regions such as Africa (2.1%) and South America (3.6%) suggests a geographical gap that needs to be addressed in future research.

3. Application Domains and Characteristics of AR Technology

Analysis of the vocational domain shows that AR is most widely applied in the fields of mechanical engineering/manufacturing (22.1%), electronics/electrical (17.1%), and health/nursing (15.4%), as shown in Table 5.

Table 5. Distribution of Vocational Fields That Utilize AR

Vocational Field	Sum	Percentage (%)
Mechanical Engineering/Manufacturing	62	22.1%
Electronics/Electrical	48	17.1%
Health/Nursing	43	15.4%
Construction/Architecture	38	13.6%
Automotive	26	9.3%
ICT/Programming	23	8.2%
Agriculture/Agribusiness	18	6.4%
Culinary/Hospitality	12	4.3%
Art/Design	10	3.6%

The high prevalence of AR implementation in technical fields such as mechanical engineering and electronics may reflect the natural suitability of AR technology for visualizing complex components, internal mechanisms, and processes that are typically difficult to observe in traditional learning environments (AlGerafi et al., 2023). The rapid increase in the application of AR for health education (15.4%) may have been driven by the need for alternative learning solutions during restrictions on access to clinical facilities during the pandemic (Kouli et al., 2022).

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In terms of the type of AR technology used, marker-based AR remained dominant (35.0%), followed by location-based AR (24.3%) and markerless AR (18.6%), as shown in Table 6.

Table 6. Types of AR Technologies Used

Types of AR Technology	Sum	Percentage (%)
Marker-based AR	98	35.0%
Location-based AR	68	24.3%
Markerless AR	52	18.6%
Projection-based AR	32	11.4%
Superimposition-based AR	30	10.7%

The dominance of marker-based AR may be due to the simplicity of its implementation and the ability to integrate it with existing learning materials such as textbooks, worksheets, and laboratory equipment (Mystakidis et al., 2022). However, the trend of increasing markerless AR reflects advancements in image recognition technology and tracking capabilities that allow for a more natural and seamless AR experience (Russo, 2021).

An analysis of AR implementation platforms (Table 7) shows the dominance of smartphones/tablets (49.3%), reflecting the wide accessibility and availability of these devices.

Table 7. AR Implementation Platform/Device

Platform/Device	Sum	Percentage (%)
Smartphone/Tablet	138	49.3%
AR Smart Glasses	64	22.9%
PC/Laptop with Webcam	42	15.0%
Custom AR Headset	26	9.3%
AR Projector	10	3.6%

Although smartphones/tablets dominate, there has been a significant increase in the use of AR smart glasses (22.9%) in recent years, reflecting the development and better accessibility of AR wearable devices (Miltiadis et al., 2025). These hands-free devices have special advantages in vocational education that often require physical manipulation of objects and the use of tools in conjunction with access to augmented information.

4. The Impact of AR on Learning Outcomes

The analysis of the impact of AR on learning outcomes shows consistent positive effects across multiple dimensions, as summarized in Table 8.

Table 8. Measured Learning Outcomes in AR Implementation

Learning Outcomes	Number of Studies	Positive Effects (%)
Psychomotor/Practical Skills	112	92.8%
Concept Understanding	98	87.7%
Motivation and Engagement	94	94.7%
Decision-making/problem-solving	72	81.9%
Memory/Retention Durability	68	89.7%
Learning Efficiency	64	78.1%
Security Awareness	48	93.8%
Collaboration	36	72.2%

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The strongest impact was seen in motivation and engagement (94.7%), psychomotor/practical skills (92.8%), and security awareness (93.8%). The high positive effect on psychomotor skills is particularly relevant for vocational education that emphasizes the development of practical skills (Chan et al., 2022). The substantial impact on security awareness (93.8%) demonstrated the potential of AR to create a safe learning environment where students can practice risky procedures without real consequences, particularly important in fields such as healthcare, manufacturing, and construction (Iqbal et al., 2022).

The effectiveness of AR also varied by vocational education level, with consistently high positive effects across all levels but highest in the context of industrial / workplace training (94.6%), as shown in Table 9.

Table 9. The Effectiveness of AR Based on Vocational Education Level

Education Level	Number of Studies	Positive Effects (%)
Vocational Secondary Education	112	89.3%
Vocational Higher Education	94	91.5%
Industry/Workplace Training	74	94.6%

The higher effectiveness of AR in the workplace context may reflect the immediate relevance and applicability of the knowledge and skills acquired, as well as the possibility of better integration with real-world work tasks and equipment (Martins et al., 2023).

5. Implementation Challenges and Pedagogical Framework

Despite its significant potential, the implementation of AR in vocational education faces various challenges, as summarized in Table 10.

Table 10. Challenges of AR Implementation in Vocational Education

Challenge	Frequency of Occurrence	Percentage (%)
Development and Infrastructure Costs	142	50.7%
Digital Competence of Teachers	126	45.0%
Curriculum Integration	108	38.6%
Technical Limitations (Devices/Connectivity)	96	34.3%
Accessibility Gap	82	29.3%
Proper Pedagogical Design	78	27.9%
Evaluation of Learning Outcomes	64	22.9%
Data Security and Privacy	46	16.4%

The most frequently mentioned challenges are related to the practical aspects of implementation: development and infrastructure costs (50.7%), teachers' digital competencies (45.0%), and curriculum integration (38.6%). These findings highlight that barriers to the adoption of AR in vocational education are not necessarily related to the technology itself, but rather to contextual, organizational, and human factors (Moencks et al., 2022).

To address these challenges and maximize the effectiveness of AR, various pedagogical frameworks have been developed and evaluated, as shown in Table 11.

Table 11. AR Pedagogy Framework in Vocational Learning

Framework Pedagogy	Number of Studies	High Effectiveness (%)
Situated Learning with AR	68	89.7%
Problem-Based Learning with AR	54	83.3%
Experiential Learning dengan AR	48	91.7%

Competency-Based Training dengan AR	42	88.1%
Cognitive Apprenticeship dengan AR	36	86.1%
Collaborative Learning with AR	32	78.1%

Experiential learning with AR showed the highest level of effectiveness (91.7%), followed by situated learning (89.7%) and competency-based training (88.1%). The high effectiveness of experiential learning with AR may be due to AR's ability to provide an immersive hands-on experience that allows students to learn through interaction and reflection (Yudiernawati et al., 2025). A natural fit between situated learning and AR is also seen, as AR can place learning in an authentic context, allowing students to connect abstract concepts with real-world situations (Utami et al., 2021).

6. Research Trends and Directions

Analysis of research trends over the period 2020-2025 (Table 12) reveals a significant shift in focus.

Table 12. AR Research Trends in Vocational Education (2020-2025)

Research Trends	Frequency 2020-2022	Frequency 2023-2025	Change (%)
Integration of AR with AI/Machine Learning	18	56	+211.1%
Multi-user Collaborative AR	24	52	+116.7%
AR for Competency Assessment	16	42	+162.5%
AR with Haptic Feedback	12	38	+216.7%
Mobile AR for Distance Learning	28	46	+64.3%
AR for Simulating the Work Environment	22	58	+163.6%
AR for Inclusive Education/Accessibility	8	32	+300.0%

The largest increase was seen in research on AR for inclusive education/accessibility (+300.0%), AR with haptic feedback (+216.7%), and AR integration with AI/machine learning (+211.1%). This trend reflects the evolution of AR technology from simple visualization tools to more sophisticated systems that integrate various sensory modalities, adaptive intelligence, and collaborative features (Devagiri et al., 2022).

Substantial increases in AR research for competency assessments (+162.5%) and work environment simulations (+163.6%) indicate a shift from using AR primarily as a learning tool to using it for authentic evaluation and preparation for real work environments (AlGerafi et al., 2023).

The highest-impact article in this area (Table 13) highlights the significance of meta-analytical studies and systematic reviews to consolidate evidence and steer research direction.

Table 13. The Highest Impact Articles in AR for Vocational Education (Top 5)

Title	Authors	Year	Citation	Journal
Augmented reality in vocational training: A systematic review of research and applications	Chiang, Feng Kuang; Shang, Xiaojing; Qiao, Lu	2022	248	Computers in Human Behavior
A systematic review of immersive virtual reality applications for higher education: Design elements,	Radianti, Jaziar; Majchrzak, Tim A.; Fromm, Jennifer; Wohlgenannt, Isabell	2020	187	Computers and Education

Title	Authors	Year	Citation	Journal
lessons learned, and research agenda				
A Systematic Literature Review: Learning with Visual by the Help of Augmented Reality Helps Students Learn Better	Liono, Rishka A.; Amanda, Nadiran; Pratiwi, Anisah; Gunawan, Alexander A.S.	2021	163	Procedia Computer Science
Augmented Reality (AR) based framework for supporting human workers in flexible manufacturing	Lotsaris, Konstantinos; Fousekis, Nikos; Koukas, Spyridon; Aivaliotis, Sotiris; Kousi, Niki; Michalos, George; Makris, Sotiris	2020	142	Procedia CIRP
The Augmented Reality Technology as Enabler for the Digitization of Industrial Business Processes: Case Studies	Bellalouna, Fahmi	2021	118	Procedia CIRP

An analysis of the five highest-impact articles in the field of AR for vocational education shows some significant research trends and focuses. Systematic review studies by Chiang et al. (2022) have the highest impact, indicating the need of the academic community and practitioners for a comprehensive synthesis of AR research and applications in vocational training. This review provides a systematic mapping of the implementation of AR for vocational skills development in various sectors.

Radianti et al., (2020) made an important contribution through a systematic review of the applications of immersive VR in higher education, which although not specifically focused on AR, has become an important reference for the development of immersive technologies in educational contexts, including vocational education. Liono et al. (2021) broaden the understanding of how AR can improve the effectiveness of visual learning, a particularly important aspect of vocational education that often requires visual demonstrations of complex processes and skills.

The last two articles focus on the implementation of AR in the context of industry and manufacturing. Lotsaris et al. (2020) developed a framework to support workers in flexible manufacturing, while Bellalouna (2021) demonstrated AR as a technology that supports the digitization of industrial business processes through case studies. These two studies show the importance of AR in bridging the gap between vocational education and industrial needs, especially in the context of Industry 4.0.

Collectively, these five articles reflect the evolution of AR research in vocational education from potential exploration and systematic review to practical implementation in an industry context. The high number of citations for these articles reflects the relevance and value of their contribution in shaping the direction of AR implementation research and practice in vocational education and training. This trend also reflects the importance of integrating AR technology to prepare a competent workforce in the era of digital transformation and Industry 4.0.

7. Conceptual Framework for the Implementation of AR in Vocational Education

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Based on the synthesis of findings from the 280 articles analyzed, a comprehensive conceptual framework for the implementation of AR in vocational education has been developed, as summarized in Table 14.

Table 14. Conceptual Framework for the Implementation of AR in Vocational Education

Implementation Dimensions	Main Components	Research Frequency
Pedagogical Design	Authentic Tasks, Scaffolding, Reflective Practice	164
AR Technology	Immersion, Interactivity, Context-awareness	152
Curriculum Integration	Learning Objectives, Assessment Alignment, Progression	138
Educator Competencies	Technical Skills, Pedagogical AR Knowledge, Support	126
Infrastructure & Support	Hardware, Software, Maintenance, Technical Support	112
Sustainability & Scalability	Cost-effectiveness, Adaptability, Transferability	94

The framework emphasizes the importance of a holistic approach to AR implementation that considers not only technological aspects but also pedagogical, curricular, and contextual elements. The most researched dimension is pedagogical design (164 studies), emphasizing that AR technology must be supported by a strong pedagogical approach that encourages authentic and reflective learning (Park & Stangl, 2020).

CONCLUSIONS

This systematic review of 280 studies on the implementation of Augmented Reality (AR) in vocational and technical education reveals a growing interest and consistent positive outcomes from AR integration, particularly between 2020 and 2023. AR has shown strong potential to enhance learning outcomes especially in psychomotor skill development, learner motivation, and engagement across key vocational fields such as engineering, electronics, and healthcare. Marker-based AR and mobile platforms like smartphones and tablets remain dominant, though more advanced solutions like markerless AR and AR smart glasses are gaining traction. The review highlights that the most effective AR implementations align with experiential and competency-based pedagogies and are most impactful when used in authentic, workplace-like environments. However, challenges remain, particularly in terms of infrastructure costs, teacher readiness, and curriculum integration.

The review offers several practical implications for educators, developers, and policymakers, including the importance of designing accessible and pedagogically aligned AR tools, strategic investment in infrastructure and teacher training, and fostering industry-academia collaboration. Future research should explore long-term impacts, inclusive and adaptive AR design, collaborative AR systems, and institutional adoption strategies. Moreover, standardization and interoperability of AR content across platforms are essential for scalability. Despite limitations such as database scope and methodological heterogeneity, this review provides a solid evidence base to inform future innovation, policy, and research in AR-enhanced vocational education.

CONFLICTS OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest regarding the publication of this article. This research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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AUTHOR CONTRIBUTIONS

Muhammad 'Ariqsyah led the systematic literature search, conducted data extraction and analysis, and prepared the initial manuscript draft. Hasan Maksum contributed to research design, provided vocational education expertise, and supervised the overall research process. Wawan Purwanto participated in article screening and quality assessment of included studies. Asrul Huda developed the search strategy and contributed to the technological aspects of the analysis framework. M Giatman provided conceptual guidance, validated research methodology, and secured institutional support. All authors discussed the research questions, reviewed findings, contributed to result interpretation, and participated in manuscript preparation and revision.

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