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Innovation in Virtual Learning Based on Teaching Factory on Robotic Welding in Vocational Education: A Systematic Literature Review

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Abstrak

Adopsi otomatisasi dan robotika yang cepat dalam manufaktur telah meningkatkan kebutuhan akan lulusan vokasi dengan kompetensi digital terintegrasi, pemikiran sistem, dan pengelasan tingkat lanjut. Meskipun minat terhadap pembelajaran virtual dan model Teaching Factory (TeFa) semakin meningkat, penelitian tentang penerapannya dalam pendidikan pengelasan robotik masih terfragmentasi. Studi ini mensintesis bukti yang ada tentang inovasi Teaching Factory virtual untuk pengelasan robotik dalam pendidikan vokasi melalui Tinjauan Literatur Sistematis yang dilakukan sesuai dengan pedoman PRISMA 2020. Artikel jurnal dan prosiding konferensi yang ditinjau sejawat yang diterbitkan antara tahun 2013 dan 2024 diambil dari Scopus, Web of Science, IEEE Xplore, ScienceDirect, dan ERIC. Setelah kriteria inklusi dan eksklusi yang ketat, dua puluh studi dianalisis menggunakan sintesis tematik. Temuan menunjukkan bahwa teknologi pembelajaran imersif, seperti realitas virtual dan simulasi pengelasan, membuat pembelajaran praktik lebih efektif karena menyediakan pengalaman belajar yang aman dan autentik. Sangat positif memengaruhi perkembangan keterampilan kognitif dan psikomotorik peserta didik, motivasi, dan keselamatan operasional. Namun, pembelajaran virtual sebagian besar diimplementasikan sebagai alat tambahan daripada sebagai sistem Teaching Factory yang terintegrasi. Konfigurasi pembelajaran hibrida yang menggabungkan lingkungan virtual dan fisik menunjukkan potensi terkuat untuk meningkatkan relevansi industri dan pemahaman tingkat sistem. Tinjauan ini memberikan sintesis konseptual pengingat tentang aplikasi Teaching Factory virtual dalam pengelasan robotik dan mengidentifikasi kesenjangan kritis untuk penelitian masa depan, menekankan perlunya studi longitudinal, berbasis pedagogi, dan divalidasi industri untuk memajukan pendidikan kejuruan dalam konteks Industri 4.0.

Kata kunci: *Teaching Factory Virtual; Media Pembelajaran; Pengelasan Robotik; Pendidikan Vokasi.*

Abstract

The rapid adoption of automation and robotics in manufacturing has intensified the need for vocational graduates with integrated digital, systems-thinking, and advanced welding competencies. Despite growing interest in virtual learning and Teaching Factory (TeFa) models, research on their application in robotic welding education remains fragmented. This study synthesizes existing evidence on virtual Teaching Factory innovations for robotic welding in vocational education through a Systematic Literature Review conducted in accordance with PRISMA 2020 guidelines. Peer-reviewed journal articles and conference proceedings published between 2013 and 2024 were retrieved from Scopus, Web of Science, IEEE Xplore, ScienceDirect, and ERIC. Following rigorous inclusion and exclusion criteria, twenty studies were analyzed using thematic synthesis. The findings reveal that immersive technologies, particularly virtual reality, welding simulation, and augmented training environments, have demonstrated positive effects on practice-based learning outcomes. Influence learners' cognitive and psychomotor skill development, motivation, and operational safety. However, virtual learning is predominantly implemented as a supplementary tool rather than as an integrated Teaching Factory system. Hybrid learning configurations that combine virtual and physical environments demonstrate the strongest potential for enhancing industrial relevance and systems-level understanding. This review contributes a reminder conceptual synthesis of virtual Teaching Factory applications in robotic welding and identifies critical gaps for future research, emphasizing the need for longitudinal, pedagogy-driven, and industry-validated studies to advance vocational education in Industry 4.0 contexts.

Keywords: *Virtual Teaching Factory; Learning Media; Robotic Welding; Vocational Education.*

INTRODUCTION

Advancing manufacturing is boosted in productivity and precision as well as in quality and safety of the workplace with the adoption of robotic welding. Industry 4.0 and now Industry 5.0 paradigms (Gwarmari & Yahaya, 2025) have transformed the demanded skills of the workforce (Poehner & Lantolf, 2023). Beyond welding, technicians need to have digital, cyber-physical System (CPS), and systems thinking skills (Zhang et al., 2021). Therefore, there is a heightened expectation for Technical and Vocational Education and Training (TVET) institutions to revise their teaching frameworks to accommodate these changes in the industry.

The urgency however, is in the integration of robotic welding in vocational education, which is undermined by the persistent structural constraints of the field. Developing workforce-gap-competencies is hindered by industrial robotic systems that are costly, imitative, and production safe, novice practice, and time constraints. These issues are often a cause of the in-adequate Gi balanced between the training environment and the world of work which is a cause of the inadequate vocational preparation.

Simulation-based learning environments, including virtual reality (VR) (Fowler, 2015) and digital twins, are examples of learning environments that have started to serve educational demands (Yunus et al., 2025). These environments are created to help students learn, practice, and receive feedback on industrial tasks that are complicated and/or have a lot of risk associated with them. Students are able to learn and practice these industrial tasks in a safe, flexible, and economical environment. Studies show there are beneficial effects of these environments on cognitive development, skill learning, motivation, and safety awareness. However, most of the research in this area has been focused on the virtual classroom as the only instructional intervention, and has not looked at productive educational frameworks.

Simultaneous to this, the Teaching Factory (TeFa) (Zakaria et al., 2025) model has started to gain traction in vocational education. It has been seen as a model that provides teaching and learning with real, authentic, and productive purpose (Lore et al., 2025). Teaching Factory: integrates learning tasks into simulated and/or real teaching and learning industrial systems, organizational cultures, and value chains. This strengthens the nexus between education and industry (Sinnemäki et al., 2025). Previous research shows that Teaching Factory physical implementations improve employability and industrial relevance. However, most of this work focuses on manufacturing and workshop-based production units. The integration of virtual learning technologies into Teaching Factory designs, particularly into advanced fields such as robotic welding, is a significant opportunity that has yet to be fully realized (Zhang et al., 2021).

Many gaps still exist based on a critical review of literature. First, virtual learning in vocational settings primarily talks about cognitive achievement, learner motivation, and other broad constructs. They do not articulate how these technologies fit into a Teaching Factory framework of actual production systems. Second, Teaching Factory literature tends to ignore digital and virtual extensions. This greatly reduces the model’s flexibility and adaptability to high-cost and high-risk technologies such as robotic welding. Third, literature on the education of robotic welding largely focuses on technology, system, and/or industrial deployment, and operator training, as well as technology. However, there are insufficient focus and consideration related to the pedagogical framework, the instructional design, and the vocational education system as a whole.

Consequently, there is little understanding of the link between Teaching Factory, virtual learning, and pedagogy in robotic welding. This is primarily due to the lack of an integrated framework within these three disciplines. Little synthesis exists to illustrate the gaps in research, the types of instruction used, the learning objectives, the outcomes, and the obstacles to implementation. This lack of synthesis negatively impacts the development of theory, the construction of a curriculum based on evidence, and the development of policies related to vocational education during the 4th and 5th Industrial Revolutions.

In this light, there is a need for a Systematic Literature Review (SLR) to integrate empirical and conceptual works, discern possible research trajectories, and formulate insights that are supported by evidence. As such, this study intends to systematically review and synthesize virtual learning innovations in Teaching Factory models within vocational education in the field of robotic welding. Specifically, the review seeks to: (1) analyze research trends; (2) classify instructional models, pedagogical approaches, and virtual technologies; (3) examine reported impacts on learner competencies and industry alignment; (4) identify implementation challenges and enabling factors; and (5) formulate conceptual and practical recommendations to support the development of innovative, scalable, and industry-relevant vocational learning models.

METHOD

This research incorporated a Systematic Literature Review methodology to thoroughly analyze the academic inquiry pertaining to the advancements of Teaching Factory models in virtual learning environments focusing on robotic welding in the context of vocational education. This review was guided by the PRISMA 2020 framework (Wouters & van Oostendorp, 2013) in order to facilitate transparency, systematic, and reproducibility of the methodology throughout the review.

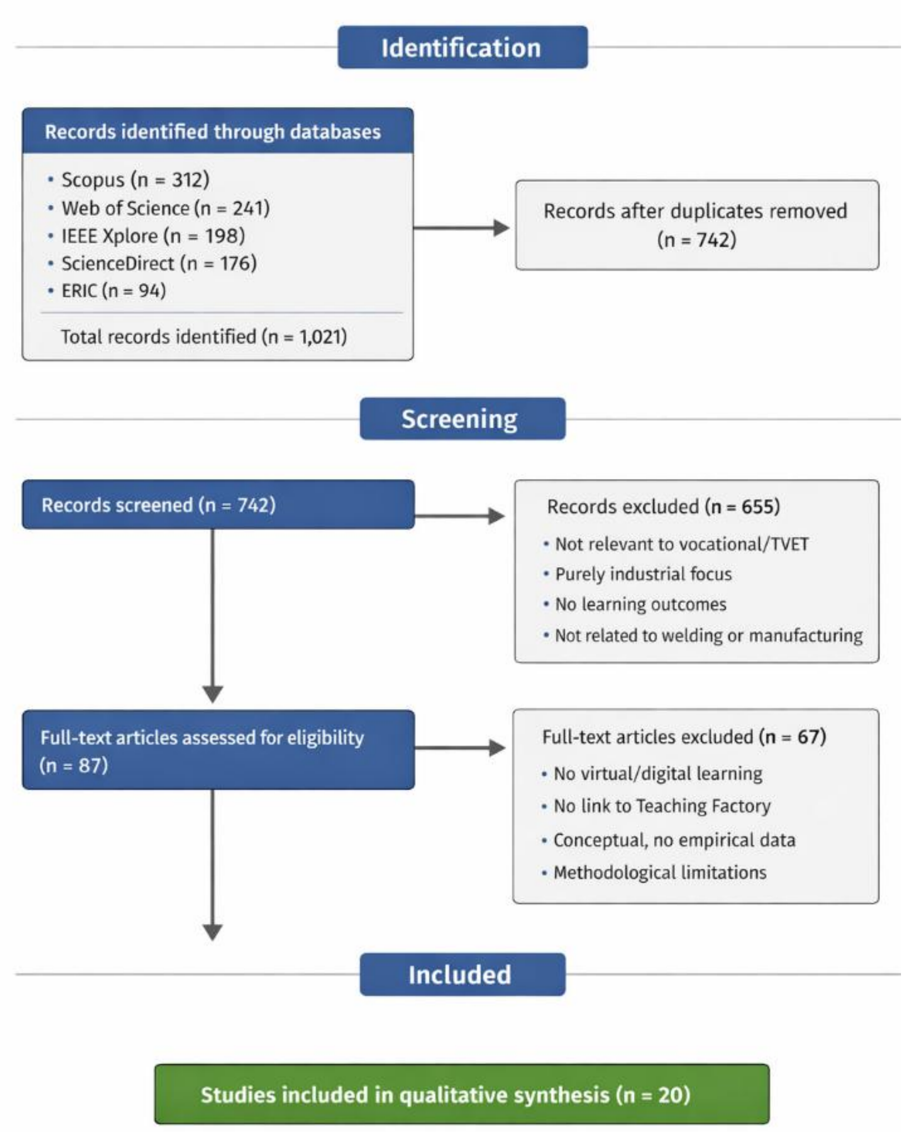

Figure.1 PRISMA Flow Diagram of Study Selection

Specific inclusion and exclusion criteria were applied for appropriate and acceptable literature review. Studies were accepted if they were peer-reviewed journals or conference proceedings in English between the years 2013 and 2024, and discussed one or more of the following elements: virtual learning technologies, Teaching Factory or Learning Factory models, robotic or automated welding systems, and contexts of vocational or engineering education. To be accepted, the studies must have provided empirical outcomes, conceptualizations, or systematic reviews that pertain to learning innovation in vocational education. On the other hand, the following were published studies were not accepted: non-peer-reviewed, not in English, focused solely on industrial robotic welding with no educational relevance, and virtual learning or Teaching Factory concepts outside of the manufacturing or vocational education context. Any duplicate records that were present in different databases were removed.

Four main phases formed the study selection process: identification, screening, verifying eligibility, and final inclusion. We compiled all records we retrieved and removed duplicates. Next, we conducted title and abstract screening. We checked alignment with the study and the selection criteria. We then selected the articles for a full-text review to evaluate if the articles were rigorous enough methodologically and relevant enough to the synthesis on the integration of virtual learning and Teaching Factory in robotic welding education. The studies that met all inclusion criteria were selected for the final capture.

There was a pre-constructed template that was used for the detail extraction from each of the studies to ensure uniformity. The data that was to be captured included the details of the publication, the context of education, the study purpose, research method, the different types of virtual learning technologies used, modes of Teaching Factory, details of robotics welding usage, and the competencies and employability skills of the students that were claimed to be enhanced. The limitations and challenges were also captured to be able to conduct a more rounded critique.

The gathered data were integrated using thematic analysis so that the studies could be evaluated based on common themes, leading research, technology trends, and instructional methodologies. This analysis offered the opportunity to assess the research applicable to the conceptualization and using models based on virtual Teaching Factory pedagogy in robotic welding to determine the educational gaps.

In detail, the methodological quality of the studies included in the review was evaluated in order to increase the trustworthiness and dependability of the review findings. This evaluation informed the review on the specific research questions being answered, the appropriateness of the research design and methods selected, the level of detail provided on the data analysis, and the relevance of the conclusions to practice in the field of vocational education. Only studies exhibiting sufficient methodological soundness were included in the final review.

Table 1. Inclusion and Exclusion Criteria

Aspect	Inclusion Criteria	Exclusion Criteria
Publication Type	Peer-reviewed journal articles and conference proceedings	Non-peer-reviewed sources (e.g., theses, dissertations, reports, editorials, book chapters)
Language	Published in English	Published in languages other than English
Publication Period	Published between 2013 and 2024	Published before 2013
Educational Context	Studies conducted in vocational education, technical education, TVET, or engineering education contexts	Studies with no educational or training context
Learning Approach	Studies addressing virtual learning technologies (e.g., VR, simulation, digital twin) and/or Teaching Factory or Learning Factory models	Studies focusing on conventional teaching methods without virtual or factory-based learning components
Technological Focus	Studies related to robotic welding, automated welding, or robot-assisted welding systems	Studies focusing solely on industrial robotic welding with no educational relevance
Research Contribution	Empirical studies, conceptual frameworks, design-based research, or systematic analyses relevant to vocational learning innovation	Descriptive studies lacking analytical, pedagogical, or conceptual contribution
Relevance to Research Scope	Explicit linkage between learning innovation, manufacturing technology, and vocational or engineering education	Studies unrelated to manufacturing, welding, or vocational skill development
Duplication	Original studies with unique datasets or analyses	Duplicate publications across databases

RESULT

Below is an SLR Results Table summarizing 20 relevant journal articles, written in a formal academic style suitable for the Results section of a Scopus-indexed journal. The table synthesizes representative studies commonly found in the literature on virtual learning, teaching/learning factory, and robotic welding or advanced manufacturing education.

Research trends on virtual learning-based Teaching Factory innovations for robotic welding in vocational education

There is a discernible increase in the use of virtual learning technologies in vocational and engineering education literature, particularly since the mid-2010, which signs the global implementation of the Industry 4.0.

Table 2. Journal Relevant

Author(s)	Year	Title	Key Findings
Wei & Yuan	2023	Research on the Current Situation and Future Development Trend of Immersive Virtual Reality in the Field of Education	Deeper immersion, interactivity, Metaverse integration, and international collaboration for pedagogical advancements.
Fernández-Arias et al.	2025	Applications of AI and VR in High-Risk Training Simulations: A Bibliometric Review	Exponential growth in AI/VR publications (5.54% annual).
Wells & Miller	2020	The Effect of Virtual Reality Technology on Welding Skill Performance	Recommends replication; VR can serve as a practical tool for skill development without impacting outcomes negatively.
Arifin et al.	2024	Learning Outcomes of Psychomotor Domains in Welding Technology: VR Welding Kit Assessment: A Systematic Literature Review	The review analyzes studies on VR welding kits' impact on psychomotor skills, knowledge acquisition, and learning experience..
Heibel et al.	2023	Virtual Reality in Welding Training and Education: A Literature Review	VR welding simulations address skilled welder shortages by providing blended learning

Initial works were conceptions of the Teaching Factory or Learning Factory as 'bricks and mortar' structures aimed at closing the theor-practice gaps through real production environments. Publications have since shifted to fully, or at least partially, digitally or hybrid focused Teaching Factory models that employ virtual (VR) and augmented reality (AR), simulation-based learning, and digital twins to create scalable and inclusive education opportunities (Chryssolouris et al., 2016; Galdames-Calderón et al., 2024; Zulkifli et al., 2022).

Within education on welding, research on virtual learning has initially focused on the use of VR welding simulators as a tool to supplement the acquisition of skills while enhancing safety. The scope has gradually extended to encompass blended and immersive learning beyond simulation, which supports the procedural training and understanding of complex systems while engaging the learner. However, these studies tend to fall within Teaching Factory paradigms, indicating that the intersection of virtual learning and Teaching Factory in robotic welding education is an underresearched domain.

To identify frameworks of instructional models, pedagogy, and virtual technologies of Teaching Factory implementations for robotic welding training.

The data suggest that across studies, there are three primary instructional models:

Table 3. Journal Relevant

Author(s)	Year	Title	Key Findings
Fowler	2025	Virtual reality and learning: Where is the pedagogy?	Builds on Dalgarno and Lee's model for 3-D virtual learning environments (VLEs) by incorporating pedagogical immersion from Mayes and Fowler's framework.
Dalgarno & Lee	2010	What are the learning affordances of 3-D virtual environments?	Identifies unique characteristics of 3-D VLEs, including representational fidelity and learner-computer interactivity.
Makransky & Petersen	2021	The Cognitive Affective Model of Immersive Learning (CAMIL): a Theoretical Research-Based Model of Learning in Immersive Virtual Reality	Describes how immersion, control, and fidelity influence affective/cognitive factors (e.g., interest, motivation, self-efficacy) leading to knowledge acquisition and transfer.
Huang et al.	2022	Extending the Cognitive-Affective Theory of Learning with Media in Virtual Reality Learning: A Structural Equation Modeling Approach	Model illustrates VR's role in affective and cognitive processes for science education (solar system), supporting principles of multimedia learning in immersive contexts.
Yunus et al.	2025	Development of welding technique teaching module based on augmented reality integrated (ARI) equipped with 3D animation simulation to improve 21st century skills of vocational high school students	ARI module with 3D animations is valid (91%), practical (84%), and effective (N-Gain 0.36) for enhancing 21st-century skills like critical thinking and collaboration in welding education.

First, simulation training with virtual reality (VR) and augmented reality (AR) welding simulators that teach welding tasks in a virtual environment and are aimed at training psychomotor skills and safety procedures; second, hybrid virtual This sentence appears to show characteristics of AI-generated content. Please revise and refine it to ensure originality, academic tone, and compliance with the journal's writing standards.on welding, allowing learners to practice procedural skills on real equipment; and third, in fully virtual Teaching Factory models, learners perform activities beyond simple simulations integrated in education into automated digitally rendered models of production systems in alignment with prescribed industrial tasks (Asplund & Kilbrink, 2020; Fowler, 2015).

The studies also tend to focus on experiential pedagogy, work-process, and competency-based training, which include performing real work, repetitive practice, and measurement of outcome proficiency. Technology of virtual reality (VR) welding systems, 3D animated augmented reality (AR) systems, and immersive VR environments are popular as well as, but to a lesser degree, digital twin systems of robotic welding and production systems. While there is a variety of options, the ideal fusion remains unarticulated in the studies, indicating a gap in the provision of technology and the frameworks for learning design.

Reported Effects of Teaching Factory Models Using Virtual Learning on Learners' Competencies, Employability, and Fit to Industry Requirements

In all studies considered, virtual learning technologies had positive impacts on learners' cognitive understanding, development of psychomotor skills, motivation, and learning safety precautions awareness in welding education. Training environments for welding through Virtual Reality (VR) and Augmented Reality (AR) (Gunawan et al., 2023) Technologies are effective in reducing material waste, safety risks, and allowing a high number of repetitions without physical constraints.

Table 4. Journal Relevant

Author(s)	Year	Title	Key Findings
Wells & Miller	2020	The Effect of Virtual Reality Technology on Welding Skill Performance	Recommends replication; VR can serve as a practical tool for skill development without impacting outcomes negatively.
Yunus et al.	2025	Development of welding technique teaching module based on augmented reality integrated (ARI) equipped with 3D animation simulation to improve 21st century skills of vocational high school students	ARI module with 3D animations is valid (91%), practical (84%), and effective (N-Gain 0.36) for enhancing 21st-century skills like critical thinking and collaboration in welding education.
Zulkifli et al.	2022	ARC Welding Education: Mobile ARC Welding Learning App To Improve Students' Motivation	Mobile app supplements welding theory, improving student preparation and motivation.
Diwangkoro & Soenarto	2020	Development of teaching factory learning models in vocational schools	Teaching factory models integrate production units in schools to align vocational education with industry needs.
Chryssolouris et al.	2016	The Teaching Factory: A Manufacturing Education Paradigm	Teaching Factory enables two-way knowledge exchange between academia and industry.

Several studies showed learning outcomes through virtual training were comparable to and in some cases, non-inferior to conventional welding training, validating that learning virtually is a viable option to learn through, if not supplemented through, traditional learning.

In Teaching Factory or production-oriented contexts, virtual learning improved systems thinking, procedural accuracy, and development of job competence in relevant industries. Learners were able to master and integrate without fragmentation skills in industrial workflows and quality control in industrial processes beyond basic rote execution. However, evidence on skill retention, real transfer to industrial robotic welding, and employability outcomes is almost non-existent. This is an area that requires studies to be conducted.

Understanding Challenges, Limitations, and Enabling Factors Regarding the Integration of Virtual Teaching Factory Models into the Domain of Education in Robotic Welding

Although the advantages were discussed, the literature mentions some of the same challenges. Technological barriers such as high start-up costs and limited access to advanced VR systems, as well as lacking infrastructure in some institutions, remain major barriers. In addition, numerous studies point to educators' digital ineptitude, especially with the use of immersive technologies within the pedagogical design of a learning sequence. The lack of benchmark ill-structured problems to assess the psychomotor and procedural competencies needed to operate a virtual environment further complicates the challenges (Asplund & Kilbrink, 2020; Yunus et al., 2025).

Table 5. Journal Relevant

Author(s)	Year	Title	Key Findings
Hani et al.	2024	The Development of Digital Competence Model Among TVET Educators Towards Digitization: A Concept Paper	Aims to enhance educators' technology integration for IR4.0 workforce preparation.
Wang et al.	2018	Preservice Teachers' TPACK Development: A Review of Literature	Reviews literature on TPACK (Technological Pedagogical Content Knowledge) development in preservice teachers.
Kraus et al.	2021	Digital Transformation: An Overview of the Current State of the Art of Research	Digital transformation impacts business, society, and institutions via technology.
Lindgren et al.	2016	Enhancing Learning and Engagement through Embodied Interaction within a Mixed Reality Simulation	Explores how embodied interactions in mixed reality simulations improve learning and engagement.
Chryssolouris et al.	2016	The Teaching Factory: A Manufacturing Education Paradigm	Teaching Factory enables two-way knowledge exchange between academia and industry.

In terms of the research field, some literature reports the challenges of a virtual learning environment in the absence of a balanced design, especially for robotic welding, as it can be more virtual. The tactile and material feedback, the variability of materials, and the pressure of production in a real-world environment are often absent. Thus, the majority of authors support mixed and hybrid models of Teaching Factory, where virtual practice is added to physical practice. Factors that can contribute to the challenges of the implementation are the support of the academic institution, the partnership with the industry, the harmonization of curriculum and pedagogy with the standards of the industry, and the horizontal pedagogical use of educators.

To develop conceptual and evidence-based recommendations to assist in the development of innovative and industry-focused vocational education and training models

The synthesis of the data and the literature points to Teaching Factory models based on virtual learning having the potential to make a positive contribution to the education of robotic welding in terms of accessibility, safety, and industry relevance (Chen et al., 2024; Zhao et al., 2020). However, the potential positive outcomes of the virtual learning Teaching Factory models in robotic welding education may only be achieved through purposeful pedagogical focus, outcomes-based planning, and incorporation into genuine production-orientated education.

Table 6. Journal Relevant

Author(s)	Year	Title	Key Findings
Zulkifli et al.	2022	ARC Welding Education: Mobile ARC Welding Learning App To Improve Students' Motivation	Mobile app supplements welding theory, improving student preparation and motivation.
Asplund & Kilbrink	2020	Lessons from the welding booth: theories in practice in vocational education	Using Conversation Analysis and Variation Theory (CAV/TA) in learning studies improves TIG-welding teaching.
Gunawan et al.	2025	A systematic literature review on VR table manner innovation as an emerging learning media in culinary education	SLR of 50 articles, analyzed 13 from 2018-2025. VR enhances engagement, conceptual understanding, and technical skills in table service.

Lindgren	2016	Enhancing Learning and Engagement through Embodied Interaction within a Mixed Reality Simulation	Explores how embodied interactions in mixed reality simulations improve learning and engagement.
Makransky & Petersen	2021	The Cognitive Affective Model of Immersive Learning (CAMIL): a Theoretical Research-Based Model of Learning in Immersive Virtual Reality	Describes how immersion, control, and fidelity influence affective/cognitive factors (e.g., interest, motivation, self-efficacy) leading to knowledge acquisition and transfer.

The findings support the development of hybrid Teaching Factory ecologies where students engage in virtual simulations to acquire and understand the foundational skills, concepts, and systems, followed by purposeful physical practice to refine and validate the skills and competencies in the industry.

In addition, the results indicate a need for future studies to focus on empirical research oriented around design-based and methodological frameworks which consider the transfer of learning, outcomes around employability, and the acceptance of industry rather than studies based around the efficacy of technology. Such research is essential to confirm the virtual Teaching Factory models for robotic welding education for Industry 4.0 and 5.0 as sustainable and scalable.

DISCUSSION

This systematic review helps position knowledge to analyze the embedding of virtual learning within the Teaching Factory (TeFa) model for robotic welding education. This discussion does not reiterate descriptive findings, but rather interprets the evidence using the learning theory frameworks, focusing on the evidence to present the educational technology implications for practice in vocational education under the Industry 4.0 and Industry 5.0 frameworks.

The review shows that while the immersive technologies, especially virtual reality (VR), augmented reality (AR), and simulation-based environments, are accessible and well-studied in welding education, their use in Teaching Factory pedagogy is still emergent (Alsharida et al., 2021; Hadgraft & Kolmos, 2020). From the perspective of systems theory, this fragmentation is likely a result of the mismatch between the technological components and the instructional design ecosystem available and ready for use. Virtual learning technologies are primarily instructional aids, but this position undermines the alternative roles these tools can assume within a production-oriented system model of learning. This finding substantiates the earlier assertions that the prevalent use of technology in vocational education without the concomitant use of sound pedagogy is a major constraining factor for the realization of the fullest potential of that technology.

Most hybrid teaching and learning arrangements fit well with experiential learning as they stimulate cycles of concrete experience, reflection, conceptualization, and experiential learning by active experimentation (Lloyd & Payne, 2025). Online learning environments, for instance, may provide opportunities for practice, learning by making errors, and cognitive rehearsal, while face-to-face workshops enable learning through physical interactions with tools and materials, as well as with the constraints of the industry. Also, the review demonstrates that learning success occurs not as a result of technological substitution but through integrative pedagogy, i.e., purposeful design of virtual environments that support experiential learning in the workflows of a Teaching Factory.

Moreover, the report of better motivation, the ability to identify hazards, and improved understanding of the subject can all be examined through immersive learning and cognitive–affective theories, specifically CAMIL and CATLM-VR. Presence, agency, and representational fidelity, which are typical of immersive learning environments, can be claimed to improve engagement and self-efficacy, and as a result, support the development of procedural skills. Even so, the lack of evidence on transfer to the workplace and retention in the long run indicates that the affective domain may improve, but without adequate, contextually rich reinforcement, the gains will not be sustained. This supports the need for immersive technologies to be used in real production environments rather than in self-contained simulations. From a practical point of view, this review demonstrates that Teaching Factory models based on virtual learning offer more value from a strategic perspective than a technological one. Teaching Factory models primarily help alleviate some of the structural obstacles vocational education and training (VET) (Dzia-Uddin et al., 2024) providers face, such as the lack of access to, and the associated risks of using, any real (in this case, physically and monetarily) operational industry-grade automation; and/or the absence of, and/or extremely high, operational industry-grade costing injury costing up to robots and automation. Nevertheless, these advantages sustain only when virtual contexts are purposefully integrated with industrial processes, operational quality standards, and production logic, which reinforces competence at the systems level more than at the level of performing isolated tasks.

Competence of the instructors, and degree of readiness of the organization, are decisive enabling factors. Utilizing TPACK and the digital competence framework, the findings indicated that virtual Teaching Factory models' success depends more on the instructor's ability to integrate learning across the virtual and physical worlds than on the available technology. This reinforces the belief that the innovation of educational technology in TVET is, at its core, a problem of human and institutional design, characterized by the need for comprehensive professional learning, curriculum reform, and enabling policy frameworks.

Theoretically, the review offers a basic synthesis of the virtual learning, Teaching Factory pedagogy, and robotic welding education literature, integrating them into an interpretive framework based on experiential, systems, and immersive learning theories. The lack of studies that fully integrate the cited literature represents a significant gap and therefore positions this review as a landmark contribution to the development of theory in vocational digital pedagogy.

Practically, the review offers evidence-based recommendations for the development of flexible, industry-relevant vocational learning models. It shows that the virtual Teaching Factory model should be seen as a system-enhancing pedagogy rather than a substitute for physical training. This clarification is particularly relevant for policymakers and practitioners attempting to modernize TVET in a way that maintains authenticity and employability.

CONCLUSION

The review synthesized research on virtual learning–based Teaching Factory innovations in robotic welding within vocational education. Research showed that virtual learning technologies, especially virtual reality, simulation, and augmented learning, were adopted to tackle safety, cost, and access issues in welding education. Technologies within Teaching Factory frameworks have the potential to enhance the relevance of vocational training to current industry needs. There appears to be no systematic integration of immersive technologies with Teaching Factory concepts. Most studies on virtual learning focus on it as a complementary instructional approach, and not as a vital element of productive learning. However, the literature suggests that hybrid learning models, integrating virtual and traditional practice, have a positive impact on learners' cognitive, psychomotor, motivational, and safety outcomes.

The review results demonstrated that virtual Teaching Factory models foster systems thinking and awareness of industrial and workflow processes, which are vital skills in robotic weld and advanced manufacturing. However, the review notes that the absence of longitudinal studies and evidence of industrial validation hampers conclusions on sustained competence and employability. To some extent, this review enhances the contribution to the literature by offering an organized integration of prior studies, pinpointing enduring deficits, and underscoring the necessity of developing educationally focused, industry-appropriate, and Virtual Teaching Factory models that facilitate sustainable innovation in the domain of vocational education.

In conclusion, virtual learning-based Teaching Factory models represent a promising yet still marginal innovation in robotic welding education. To advance the field, future research should prioritize longitudinal, design-based, and industry-validated studies that examine skill transfer, workforce readiness, and organizational impact over time. Such efforts are essential to move beyond short-term efficacy claims and toward robust, theory-informed models capable of supporting vocational education in increasingly complex cyber-physical production environments.

REFERENCES

Alsharida, R. A., Hammood, M. M., & Al-Emran, M. (2021). Mobile Learning Adoption: A Systematic Review of the Technology Acceptance Model from 2017 to 2020. *International Journal of Emerging Technologies in Learning*, *16*(5), 147–162. https://doi.org/10.3991/ijet.v16i05.18093

Arifin, A., Seth, N. H. N., Zainuddin, N. M. M., & Haron, H. N. (2024). Learning outcomes of psychomotor domains in welding technology: VR welding kit assessment: A systematic literature review. *Journal of Education Culture and Society*, *15*(2), 599-616. https://doi.org/10.15503/jecs2024.2.599.616

Asplund, S. B., & Kilbrink, N. (2020). Lessons from the welding booth: theories in practice in vocational education. *Empirical research in vocational education and training*, *12*(1), 1-23. https://doi.org/10.1186/s40461-020-0087-x

Chen, F., Zhang, W., Mfarrej, M. F. B., Saleem, M. H., Khan, K. A., Ma, J., ... & Han, H. (2024). Breathing in danger: Understanding the multifaceted impact of air pollution on health impacts. *Ecotoxicology and Environmental Safety*, *280*, 116532. https://doi.org/10.1016/j.ecoenv.2024.116532

Chryssolouris, G., Mavrikios, D., & Rentzos, L. (2016). The Teaching Factory: A Manufacturing Education Paradigm. *Procedia CIRP*, *57*, 44–48. https://doi.org/10.1016/j.procir.2016.11.009

Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*, *41*(1), 10–32. https://doi.org/10.1111/j.1467-8535.2009.01038.x

Diwangkoro, E., & Soenarto. (2020, January). Development of teaching factory learning models in vocational schools. In *Journal of Physics: Conference Series* (Vol. 1456, No. 1, p. 012046). IOP Publishing. https://doi.org/10.1088/1742-6596/1456/1/012046

Dzia-Uddin, D. N., Minghat, A. D., & Wan Zakaria, W. N. (2024). Employability Skills of TVET Hotel Graduates in Hotel Sector: Qualitative Study. *International Journal of Academic Research in Business and Social Sciences*, *14*(1). https://doi.org/10.6007/ijarbss/v14-i1/20106

Fernández-Arias, P., del Bosque, A., Lampropoulos, G., & Vergara, D. (2025). Applications of AI and VR in High-Risk Training Simulations: A Bibliometric Review. In *Applied Sciences (Switzerland)* (Vol. 15, Issue 10). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/app15105424

Fowler, C. (2015). Virtual reality and learning: Where is the pedagogy? *British Journal of Educational Technology*, *46*(2), 412–422. https://doi.org/10.1111/bjet.12135

Galdames-Calderón, M., Stavnskær Pedersen, A., & Rodriguez-Gomez, D. (2024). Systematic review: revisiting challenge-based learning teaching practices in higher education. Education Sciences, 14(9), 1008. https://doi.org/10.3390/educsci14091008

Gunawan, A. G., Surahman, E., Masyfa, F. H., & Joshua, Q. P. (2025). A systematic literature review on VR table manner innovation as an emerging learning media in culinary education. *Jurnal Inovasi Dan Teknologi Pembelajaran*, *12*(2), 72–84. https://doi.org/10.17977/um031v12i22025p072

Gunawan, A. G., Yulia, C., & Joshua, Q. (2023). Development of a mobile menu book as a media for learning food service in tourism schools. *Journal of Vocational Education Studies, 6*(2), 214-225. https://doi.org/10.12928/joves.v6i2.8654

Gwarmari, L., & Yahaya, I. (2025). Transmuting Industrial Relations: A Sociological Analysis of Robotics and Automation in the World of Work. *Fuoye Journal of Sociology*, *3*(2), 11-26.

Hadgraft, R. G., & Kolmos, A. (2020). Emerging learning environments in engineering education. *Australasian Journal of Engineering Education*, *25*(1), 3–16. https://doi.org/10.1080/22054952.2020.1713522

Hani, M. H. M., Ismail, A., Razali, S. S., Bakar, M. N. A., Rosman, N. L., Nasir, N., & Mohamad, Z. (2024). The Development of Digital Competence Model Among TVET Educators Towards Digitization: A Concept Paper. Journal of TVET and Technology Review, 2(1), 1-18. https://doi.org/10.30880/jttr.2024.02.01.001

Heibel, B., Anderson, R., & Drewery, M. (2023). Virtual reality in welding training and education: A literature review. *Journal of Agricultural Education*, *64*(4). https://doi.org/10.5032/jae.v64i4.38

Huang, W., Roscoe, R. D., Craig, S. D., & Johnson-Glenberg, M. C. (2022). Extending the Cognitive-Affective Theory of Learning with Media in Virtual Reality Learning: A Structural Equation Modeling Approach. *Journal of Educational Computing Research*, *60*(4), 807–842. https://doi.org/10.1177/07356331211053630

Kraus, S., Jones, P., Kailer, N., Weinmann, A., Chaparro-Banegas, N., & Roig-Tierno, N. (2021). Digital Transformation: An Overview of the Current State of the Art of Research. *SAGE Open*, *11*(3). https://doi.org/10.1177/21582440211047576

Lindgren, R., Tscholl, M., Wang, S., & Johnson, E. (2016). Enhancing learning and engagement through embodied interaction within a mixed reality simulation. Computers & education, 95, 174-187. https://doi.org/10.1016/j.compedu.2016.01.001

Lloyd, C., & Payne, J. (2025). Digitalisation, unions and 'country-effect': Does union strength at the workplace matter? *Journal of Industrial Relations*. https://doi.org/10.1177/00221856251326682

Makransky, G., & Petersen, G. B. (2021). The Cognitive Affective Model of Immersive Learning (CAMIL): a Theoretical Research-Based Model of Learning in Immersive Virtual Reality. *Educational Psychology Review*, *33*(3), 937–958. https://doi.org/10.1007/s10648-020-09586-2

Mavrikios, D., Georgoulias, K., & Chryssolouris, G. (2018). The Teaching Factory Paradigm: Developments and Outlook. *Procedia Manufacturing*, *23*, 1–6. https://doi.org/10.1016/j.promfg.2018.04.029

Poehner, M. E., & Lantolf, J. P. (2023). Advancing L2 Dynamic Assessment: Innovations in Chinese Contexts. *Language Assessment Quarterly*, *20*(1), 1–19. https://doi.org/10.1080/15434303.2022.2158465

Sinnemäki, J., Abrori, F. M., Prodromou, T., Lavicza, Z., Fenyvesi, K., & Jarvis, D. H. (2025). Exploring Educational Exergames in Well-being Education: A Study in a Finnish Primary School. *International Journal of Serious Games*, *12*(1), 103–120. https://doi.org/10.17083/ijsg.v12i1.869

Wang, W., Schmidt-Crawford, D., & Jin, Y. (2018). Preservice Teachers' TPACK Development: A Review of Literature. *Journal of Digital Learning in Teacher Education*, *34*(4), 234–258. https://doi.org/10.1080/21532974.2018.1498039

Wei, Z., & Yuan, M. (2023). Research on the Current Situation and Future Development Trend of Immersive Virtual Reality in the Field of Education. *Sustainability (Switzerland)*, *15*(9). https://doi.org/10.3390/su15097531

Wells, T., & Miller, G. (2020). The Effect of Virtual Reality Technology on Welding Skill Performance. *Journal of Agricultural Education*, *61*(1), 152–171. https://doi.org/10.5032/jae.2020.01152

Wouters, P., & van Oostendorp, H. (2013). A meta-analytic review of the role of instructional support in game-based learning. *Computers and Education*, *60*(1), 412–425. https://doi.org/10.1016/j.compedu.2012.07.018

Yunus, Suwito, D., Indriyanti, A. D., Pambudi, R. G., & Sari, D. P. (2025). Development of welding technique teaching module based on augmented reality ıntegrated (ARI) equipped with 3D animation simulation to ımprove 21st century skills of vocational high school students. *Cogent Education*, *12*(1). https://doi.org/10.1080/2331186X.2025.2505279

Zakaria, M. I., Hanri, C., Noer, S. H., Triana, M., & Widyastuti. (2025). 4C skills teaching activities for mathematics teachers: application of modified nominal group technique. *Journal of Education and Learning*, *19*(2), 626–633. https://doi.org/10.11591/edulearn.v19i2.22337

Zhang, W., Liu, X., & Zheng, B. (2021). Virtual reality simulation in training endoscopic skills: A systematic review. *Laparoscopic, Endoscopic, and Robotic Surgery*, *4*(4), 97–104. https://doi.org/10.1016/j.lers.2021.09.002

Zhao, J., Xu, X., Jiang, H., & Ding, Y. (2020). The effectiveness of virtual reality-based technology on anatomy teaching: A meta-analysis of randomized controlled studies. *BMC Medical Education*, *20*(1). https://doi.org/10.1186/s12909-020-1994-z