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Implementation of Deep Learning in Teaching Factory as a Strategy for Enhancing Industrial Competencies: A Systematic Literature Review

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ABSTRACT: The advancement of Industry 4.0 has significantly increased the demand for industrial competencies aligned with intelligent, data-driven manufacturing systems. Deep learning, as a core artificial intelligence technology, plays a critical role in smart factories, particularly in computer vision, predictive analytics, and automated decision-making. In parallel, the Teaching Factory model has emerged as a strategic educational approach to bridge the gap between vocational education and real industrial practices. This study conducts a Systematic Literature Review (SLR) on the integration of deep learning and pedagogical approaches within Teaching Factory and automated manufacturing learning environments, with a focus on industrial competency development. Using a structured and transparent review protocol, peer-reviewed journal articles were analyzed to identify instructional practices, learning theories, targeted competencies, and research methodologies. The review indicates that while Teaching Factory models emphasize production-based learning, deep learning has not yet been systematically embedded into their pedagogical frameworks. Existing studies predominantly address technical and cognitive competencies, with limited attention to transversal and employability competencies. Methodologically, the literature is largely dominated by conceptual frameworks and short-term case studies, underscoring the need for more empirical and longitudinal research. This review contributes by synthesizing current evidence, clarifying research gaps, and proposing directions for pedagogically grounded and industry-aligned Teaching Factory models that integrate deep learning to support comprehensive industrial competency development.

Keywords: Teaching Factory, Deep Learning, Education

INTRODUCTION

The integration of artificial intelligence (AI), automation, and data-driven decision-making within Industry 4.0 has triggered unprecedented advances in industrial operations. Of the fields of AI, deep learning has emerged as fundamental for the creation of intelligent systems and applications in computer vision, predictive maintenance, quality assessment, and process optimization (AG. Gunawan, 2025; Gustiana Gunawan et al., 2025). Developments and transformations in such areas have altered the workforce in the industrial sector, creating a need for additional competencies in the workforce such as being able to work with adaptive intelligent systems. With the advent of these changes, educational institutions, and in particular those focused on technical vocational education and training (TVET) (Ariawan et al., 2025; Powell et al., 2024), are being prompted to rethink their pedagogical approaches. This is to ensure that the outcome of learning in their institutions retains currency and relevance in the industry. The Teaching Factory model has emerged as a relevant pedagogical framework that provides experiential learning opportunities to students by blending real industrial processes, production systems, and problem-solving activities within their learning. Teaching Factory seeks to address the challenges that arise from a purely theoretical pedagogical approach by using industrial production systems in a simulation or real manner.

Teaching Factories, within the scope of the Industry 4.0 paradigm, allow learners to acquire non-technical and technical industrial skills. Automation, intelligent data analysis, and real-time decision-making support allow students to interface with real industrial data and tech, and, at the same time, advance their analytical skills and technical competencies (Chryssolouris et al., 2016; Diwangkoro & Soenarto, 2020). Interdisciplinary research on deep learning–enabled Teaching Factory models for industrial competency development has attracted substantial interest; however, the field remains in its early stages. This is reflected in the wide variation in research designs, implementation approaches, pedagogical frameworks, and assessment methods reported in existing studies. As such, there is a need to understand the current state of research concerning Teaching Factories and its impact on the industrial competencies development through deep learning, and its diverse forms (Cornelia Tjiptady, 2019; Subekti et al., n.d.).

While there is abundant research on deep learning in industry and, separately, Teaching Factory model effectiveness in vocational education, there is a lack of studies to systematically address the intersection of the two. Most of the analyses in the available literature focus on the technical aspects, the performance of the deep learning algorithms, and, on the other hand, the pedagogical results of Teaching Factory systems, without sufficient focus on the deep learning embedded Teaching Factory systems.

In addition, there is insufficient analysis on the kinds of industrial competencies, technical, cognitive, and employability, cultivated in Teaching Factory environments augmented with deep learning. The differing contexts of implementation, education levels and fields of industry further complicate the discrepancies. Thus, the lack of a singular structure or synthesis based on evidence brings obstacles to the hands of educators, policymakers, and researchers in understanding the preferred practices, obstacles, and prospects of this developing area. This is a gap that a Systematic Literature Review aims to address, specifically to trace the patterns in the research, the methodologies used, and the unaddressed questions that arise when deep learning is incorporated into Teaching Factory environments.

By systematically reviewing and synthesizing existing studies on the role of deep learning in Teaching Factory models for industrial skill development, this study identifies key application domains and technological pathways, while critically examining the limitations of current pedagogical integrations of deep learning, and assess the extent to which learners' industrial skills and competencies are transformed. It also seeks to construct a conceptual framework that addresses the unqualified use of pedagogical deep learning, the Teaching Factory model, and industrial skill development pedagogical techniques within the framework of Industry 4.0.

METHOD

The methodological contribution of this study lies in the use of a structured and integrative literature review approach to examine how deep learning is applied within Teaching Factory models, as a systematic literature review of the use of Teaching Factory implemented deep learning is a highly interdisciplinary activity and is approached here as one of the teaching post reviews (Borenstein et al., 2011; Gunawan et al., 2025; Wouters & Van Oostendorp, 2013). Moreover, this research, unlike previous reviews, which are predominantly focused on the use of artificial intelligence in education, has included a review in the area of the Teaching Factory, and, therefore, has incorporated multiple diverse reviews into one.

First, this review is aimed at extending the SLR process model of deep learning to the different algorithms and technical functions employed. Advances in technology and the use of diverse deep learning algorithms can be classified into Teaching Factory processes, and, in this review, the processes of production planning, quality control, predictive maintenance, and human-machine interaction will be discussed. This understanding of the employed technology will help to, at least partially, contextualize the ways in which the employed deep learning technologies are integrated into the genuine industrial learning environments, rather than merely as academic tools.

Second, the study proposes a competency-based integrated synthesis framework from the deep learning-enabled Teaching Factory systems. This framework differentiates the levels of industrial competencies to be attained such as technical, cognitive, analytical, problem-solving, and other employability skills. This deep learning-enabled Teaching Factory system review framework goes beyond the mere description of academic knowledge and establishes the link between the learning outcomes and the technologies embedded to illustrate the mechanisms of competency development.

This research includes a level-by-level, industry-by-industry, and context-by-context comparative methodological analysis. It helps contextualize the enabling and constraining factors for effectiveness and scalability of deep learning in Teaching Factory models. The cohesion of disparate contextual factors in literature has been ignored for years. Most publications describe single case studies without comparative analysis.

Finally, the study has a methodological contribution in demonstrating how previous research has categorized design of study, research instruments, and evaluation criteria. This reveals gaps and inconsistencies in the methodologies used. This helps construct a roadmap for future empirical research and the design of pedagogically and industrially relevant Teaching Factory models incorporating deep learning.

RESULT AND DISCUSSION

Although scholarly review indicates that there is interest regarding integration of deep learning into Teaching Factory Models pertaining to Industry 4.0 Education, there is still insufficient attention given to this intersection. This is shown in academic studies from fields as varied as education engineering, technical vocational education and training (TVET), industrial engineering and applied artificial intelligence.

Table 1. Journal Relevant

Author(s)	Title	Novelty
(Berry et al., 1994)	Improving the Quality of Vocational Education in the 4.0 Industrial Revolution by using the Teaching Factory Approach	Introduces three distinct teaching factory models to enhance vocational education in response to Industry 4.0 challenges, emphasizing practical industry-school collaborations for skill development and brain optimization.
(Hidayat Martawijaya, 2012)	Developing A Teaching Factory Learning Model To Improve Production Competencies Among Mechanical Engineering Students In A Vocational Senior High School	Proposes a novel six-step Teaching Factory (TF-6M) model validated through experiments, demonstrating improved student competencies, motivation, and work ethics via in-school industrial experiences.
(Kipper et al., 2021)	Scientific mapping to identify competencies required by industry 4.0	Uses scientific mapping (via SciMAT software) on literature from 2010–2018 to identify key skills (e.g., leadership, problem-solving) and knowledge areas for Industry 4.0, advocating for "learning factories" to integrate education with industry needs.
(Roll & Wylie, 2016)	Evolution and Revolution in Artificial Intelligence in Education	Analyzes 47 papers from the Journal of AIED (1994, 2004, 2014) to trace AIED evolution, proposing two research strands: evolutionary (classroom-focused) and revolutionary (embedding AI in everyday student life for cultural and community support).
(Benešová & Tupa, 2017)	Requirements for Education and Qualification of People in Industry 4.0	Identifies job roles and qualification needs in Industry 4.0 contexts, emphasizing the impact of digitalization and robotics on labor markets and education systems, with

		a focus on adapting to high financial and skill gaps.
(Vieira et al., 2022)	Interdisciplinary Teaching Activities for High School Integrated to Vocational Education Promoting Reflections on Industry 4.0 Technologies and Their Implication in Society	Develops and applies an action-research-based educational product for vocational high school students, integrating history, technologies (e.g., IoT, data mining), and societal impacts of Industry 4.0 to foster critical thinking and polytechnic formation.
(Zawacki-Richter et al., 2019)	Systematic review of research on artificial intelligence applications in higher education – where are the educators?	Conducts a systematic review of 146 articles (2007–2018) on AI in higher education, categorizing applications into profiling/prediction, assessment, adaptive systems, and intelligent tutoring; highlights gaps in ethical, pedagogical, and educator-focused research.
(Ghobakhloo, 2018)	The future of manufacturing industry: a strategic roadmap toward Industry 4.0	Performs a content-centric review of 178 documents to derive 12 design principles and 14 technology trends for Industry 4.0, proposing a customized strategic roadmap for manufacturers' transition, emphasizing idiosyncratic strategies based on company capabilities.
(Abele et al., 2015)	Learning Factories for research, education, and training	Defines "Learning Factory" and develops a morphology with seven dimensions, outlining six application scenarios (e.g., training, education, research) to address industry challenges like adaptability and competency development in realistic environments.
(Tisch et al., 2016)	Learning factory design: a competency-oriented approach integrating three design levels	Introduces a competency-oriented design framework for learning factories, integrating three levels (macro, meso, micro) to align with educational goals, addressing gaps in traditional teaching methods for manufacturing competencies.
(Kamble et al., 2018)	Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives	Reviews 85 papers to propose a sustainable Industry 4.0 framework with technologies, process integration, and outcomes; categorizes research into human-machine/tech interactions and sustainability, offering future directions like process safety and big data.
(Xu, 2020)	The contribution of systems science to Industry 4.0	Explores systems science's role in managing Industry 4.0 complexity, linking it to enabling technologies (e.g., IoT, CPS) and advocating for its application in industrial integration and ecosystems for the Fourth Industrial Revolution.

(Wang & Raj, 2017)	On the Origin of Deep Learning	Traces the evolutionary history of deep learning models (e.g., CNN, DBN, RNN) from neural network origins in associationism, summarizing milestones and proposing future research directions like biological inspirations and computational trade-offs.
(Kahveci et al., 2022)	An end-to-end big data analytics platform for IoT-enabled smart factories: A case study of battery module assembly system for electric vehicles	Develops a five-layer IoT-based big data analytics platform (acquisition to visualization) for smart factories, demonstrated in an electric vehicle battery assembly system, integrating tools for decision-making, quality improvement, and Industry 4.0 resilience.
(Kautsar et al., 2022)	Teaching Factory Model Development in Vocational High Schools	Develops a 9-component conceptual model for teaching factories in vocational high schools using a 4-D R&D approach, validated for feasibility, with emphasis on legal foundations, independent financial management, and sustainability.
(Ahmad et al., 2019)	Deep Learning Methods and Applications	Reviews deep learning paradigms (e.g., CNN, RNN, LSTM) and their applications across fields like image recognition and NLP, emphasizing knowledge reuse and enhanced predictive capabilities enabled by big data and algorithms.
(Rentzos et al., 2015)	A Two-way Knowledge Interaction in Manufacturing Education: the Teaching Factory	Presents the evolution of the Teaching Factory with two-way knowledge exchange between academia and industry via ICT, demonstrated through two industrial pilots showing benefits for innovation and real-life project integration.
(Pratama et al., 2025)	A Systematic Literature Review on Implementation of Teaching Factory Model in Vocational Education	Conducts an SLR on TeFa models using Scopus data, identifying innovations, positive impacts on students/schools/industry, core competencies, and challenges from education/business perspectives, proposing future innovative frameworks.
(Mavrikios et al., 2019)	The Teaching Factory Network: A new collaborative paradigm for manufacturing education	Introduces the Teaching Factory Network (TFN) as a scalable, non-geographical collaborative paradigm linking academic and industrial entities via a software platform to address modern manufacturing education challenges.
(Mavrikios et al., 2018)	The Teaching Factory Paradigm: Developments and Outlook	Outlines developments in the Teaching Factory paradigm, including industrial pilots, and proposes the Teaching Factory

	Network (TFN) as an elevated network-based approach to match training demands with offers across actors.

The studies considered thank Teaching Factory and Learning Factory concepts primarily developed to fill in gaps in the literature left by digitalization, automation and intelligent manufacturing system studies. Foundational studies discuss the shift from traditional vocational education to educational production models and industry partnerships to create a workplace learning environments that simulate real industry processes. These environments allow learners to gain experience in embedding problem-solving and a career-oriented work ethic in alignment with Industry 4.0. Several studies consider competency-oriented frameworks as the key outcome from the Teaching Factory. Research primarily focused on learning factory design suggests multi-level models from macro curriculum alignment to micro learning activities, in order for specific industrial competencies to be purposefully designed within instructional design. These competencies were suggested to be primarily non-technical and encompass cognitive competencies in analysis, decision making, leadership, flexibility and other adaptability (Firman Nurdiyansyah Sunandar et al., 2025; Roll & Wylie, 2016). Additional studies using systematic mapping processes, and systematic reviews have suggested that there is a strong need for such transversal competencies within educational frameworks, and that there is a clear need for these competencies to have a framework developed for them in order that educational models be considered fit for Industry 4.0. In tandem, the growing importance of artificial intelligence and deep learning as facilitating tools in smart manufacturing and education domains also becomes apparent in the literature. While only a few studies discuss deep learning in Teaching Factory contexts(Hidayat Martawijaya, 2012), a number of papers present strong conceptual and technological bases. Deep learning is identified as one of the main components of intelligent systems that aid smart factories in machine vision, data abstraction, the forecasting of behaviours, and automated decisions. Such systems offer Teaching Factory settings the chance to implement authentic learning activities powered by AI for industrial purposes.

The educational innovation perspective also compels a view that AI and data analytics are moving as adjunct teaching tools to be integrated within learning systems. Systematic reviews on the subject of artificial intelligence in education elucidate that the greater majority of instances centre on adaption, assessment, and intelligent tutoring systems, and that frameworks relying on the teacher as a primary pedagogical agent are still, to a certain extent, vastly unexplored. From this perspective, Teaching Factory is paramount as a contextual conduit for the intended application of deep learning technologies in production-based learning systems, rather than in siloed, static applications (Abele et al., 2015; Elmqaddem, 2019).

Conceptual modeling, case study analysis, systematic literature reviews, and design-based research comprise the methodological toolkit in the studies under review. Performance and competency (empirical) validation takes place within vocational education and training, polytechnic and industrial pilot centres. There is a lack of longitudinal and experimental study work about the fostering of competencies and employability the targeted studies seek to work on.

The results show that Teaching Factory models facilitate the pedagogical integration of Fourth Industrial Revolution technologies, with deep learning emerging as a key enabling approach. The literature captures the possibility to combine a competency-based Teaching Factory model with a smart, data-oriented pedagogical model. However, the studies show a need. There is little foundational work that seeks to explore the use of deep learning technologies in Teaching Factory settings to develop competencies.

The review systematized in this document reveals that Teaching Factory and Learning Factory models have been acknowledged as pedagogical strategies that balance vocational and engineering education with the requirements of Industry 4.0 (Haipeter, 2020; Wardina et al., 2019; Xu, 2020). As with other conceptual and empirical reviews, the literature analyzed here confirms that production-based learning environments strengthen the cognitive and technical competencies as students engage with real industrial processes. Therefore, the Teaching Factory continues to serve as a structural intermediary between educational systems and the complexities of modern manufacturing systems.

This review highlights a primary observation: while the influence of artificial intelligence and deep learning on smart manufacturing systems is increasingly evident, the direct and explicit infusion of these elements into Teaching Factory models remains scarce and peripheral. The majority of the literature highlights the sophisticated design of competencies, collaboration with industry(Ghobakhloo, 2018), and experiential learning frameworks, while the notion of deep learning remains absent as a genuine instructional or workflow component. Whereas literature on Industry 4.0 and smart factories incorporates the concept of deep learning, it is usually to emphasize the technological potential and is rarely to suggest it as a pedagogical element of a Teaching Factory (Ouanhlee, 2024). The absence of deep learning in this context confirms the gap in the research and suggests the need to study the pedagogical frameworks that enable a Teaching Factory, along with deep learning, as a significant undertaking.

Skill and competency development in the Teaching Factory context goes beyond the development of technical skills to include complex and higher-order thinking and transversal competencies, including but not limited to, problem-solving, decision-making, and leadership and adaptability. The lack of unified competency models and competency assessment tools across studies also presents limitations on the degree of comparability and generalizability of the findings. These limitations of the data collected underscore the necessity of competence synthesizing models as outlined in this esay in linking synthesis to the application of deep learning models to specific competencies in industry.

The placement of deep learning technologies on pedagogy also deserves mention (Basar, 2019; Carney, 2022; Frey & Osborne, 2017). The most comprehensive systematic review on Artificial Intelligence in education focuses on adaptive learning technologies and intelligent tutoring and automated assessment without much consideration to the teacher and the instructional design. On the other hand, Teaching Factory context is where deep learning is used most appropriately as it is part of a real production system and enables learners to engage with intelligent technologies as expected in an industry. It is this difference in pedagogy that separates Teaching Factory AI from other AI in classroom integration and points to the potential for profound learning.

From a methodological lens, the field's fascination with case study, conceptual model, and design-based research reflects the preliminary phase of this field. While such research offers insights into the ability to implement and the contextual peculiarities, the absence of longitudinal and experimental research limits our understanding of the persistence of competencies and workforce preparedness. Future research should be directed towards the more elaborate and rigorous designs of research that would be focused on the sustained effects of the deep learning–enabled Teaching Factory models on graduate employability and productivity of the industry.

Lastly, the literature review indicates continuous challenges in implementation, such as inadequate infrastructure, expensive technology, and the lack of teacher proficiency in deep learning. These factors indicate that the successful incorporation of these elements requires more than just technological preparedness. It demands institutional work, curriculum adjustment, and training of the teaching staff. It is important to overcome these challenges to ensure that deep learning is a purposefully integrative technology for enhancing the development of competencies demanded by industry and not merely an add-on.

In summary, this supportive discussion confirms that Teaching Factory models offer an excellent pedagogical foundation for incorporating advanced industrial competencies enhancement. The literature offers a clear need for additional pedagogically sound, competencies-focused, empirically validated research that examines the role of deep learning in Teaching Factory ecosystems. This study contributes to the literature by analyzing the current research trends, highlighting the relevant voids, and proposing a roadmap for future research at the nexus of deep learning, Teaching Factory, and Industry 4.0 education.

CONCLUSION

The Systematic Literature Review examines Teaching Factory and Learning Factory models and situates them within the pedagogical context of Industry 4.0 and more specifically, the role of artificial intelligence and deep learning. The evidence suggests that the Teaching Factory models have been consistently reported as effective methods of pedagogy for the development of industrial competencies via production and learning within an industry driven educational context. They bridge the pedagogy–practice gaps, as learners are engaged in authentic workflows, decision-making, and task-oriented competencies of the industrial world.

Nonetheless, the review also points that the integration of deep learning pedagogy within Teaching Factory environments is absent. While deep learning is precisely the foundational technology within smart manufacturing and Industry 4.0, it is not present within Teaching Factory environments, leaving technology, the pedagogy, and practice isolated. This schism suggests that advanced technologies and instructional design have deep learning insufficiently integrated for it to be fully effective in the construction of competencies.

Moreover, there is an apparent appreciation of technical and cognitive skills in the literature, while the employability and transversal skills are not as rigorously evaluated. The methodological variety of the literature—specifically the preponderance of case studies and design-based research—offers important contextual details, but impedes generalizability and assessing impact over time. All in all, this review illustrates the likely prospects of Teaching Factory models harnessing deep learning, but also calls for relatively more focused, competency-based, and rigorous studies.

The present study, on the other hand, advances theory in vocational and engineering education literature by situating the Teaching Factory as a pedagogical hub for the fusion of deep learning and technologies of the Fourth Industrial Revolution. The findings lend credence to the extension of the theory of competency-based learning by viewing the intelligent, data-driven systems as learning environment constituents, and not merely as tools. This, in turn, paves the way for models that tangibly connect deep learning with the desired competencies in a given industry.

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