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MANAGING INDUSTRY 4.0 COMPETENCIES FOR THE DIGITAL ECONOMY: INDUSTRIAL ROBOTICS AND UNIVERSITY-INDUSTRY COLLABORATION IN ENGINEERING EDUCATION

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ABSTRACT

The digital economy and Industry 4.0 have reshaped the competencies required of engineering graduates. Employers increasingly seek professionals who combine technical knowledge with systems thinking process awareness, analytical adaptability, and the capacity to work in technologically advanced environments. This shift presents a strategic challenge for higher education institutions, which must ensure that competency development remains aligned with labour market needs. This paper examines how industrial robotics and university-industry collaboration can support the development and management of Industry 4.0 competencies in engineering education. Using a qualitative case study approach, the research focuses on an educational intervention conducted at a private university in southern Poland. The intervention integrated robotics-based laboratory activities with a structured study visit to a manufacturing company. The findings suggest that hands-on experience with an industrial robot, combined with direct exposure to real production processes, enhances students' understanding of industrial workflows, increases engagement, strengthens career awareness, and supports the acquisition of skills relevant to the digital economy. The paper concludes that such initiatives should be viewed not only as teaching improvements, but also as strategic managerial responses to the need for curriculum relevance, stakeholder cooperation, knowledge transfer, and quality-oriented adaptation in higher education.

Keywords: *digital economy, Industry 4.0, competency management, engineering education, industrial robotics, university-industry collaboration, experiential learning, higher education quality*

1. INTRODUCTION

The new economy is shaped by digitalisation, automation, advanced data processing, cyber-physical systems, artificial intelligence and the growing interdependence between technology, organisation, and human capital. These developments affect not only how value is created in industry, but also how universities are expected to prepare graduates for professional roles. In engineering fields, this challenge is particularly visible, as the competencies required in contemporary production systems increasingly extend beyond traditional technical knowledge. Graduates are now expected to understand how automation functions within broader process structures, how production logic is connected to organisational goals, and how digital tools influence decision-making, quality, and coordination. In this context, higher education institutions can no longer rely solely on lecture-based teaching or fragmented technical content. As labour markets increasingly demand adaptive, competent, and practice-oriented engineers, universities must design educational processes that deliberately support the development of these competencies. This issue is especially relevant to management and quality sciences, as competency development is not merely a pedagogical concern, but also an organisational challenge. It involves identifying stakeholder expectations, managing educational resources, structuring learning environments, and ensuring that teaching remains responsive to social and economic change. The concept of Industry 4.0 has intensified debate on the future of engineering education. It highlights the need for stronger integration between technical knowledge, digital infrastructure, process understanding, and industrial practice. Universities are increasingly expected to modernise curricula, update laboratory infrastructure, cooperate with external partners, and create practice-based learning environments. However, access to modern equipment alone is insufficient. Educational activities must be designed so that students can connect theoretical knowledge with authentic technological and organisational contexts. University-industry collaboration is one of the most promising mechanisms for supporting this transition. Industrial partners can provide access to current technologies, real process standards, and practical expectations regarding graduate competencies. Universities, in turn, can translate this knowledge into structured educational experiences. Among the available forms of collaboration, two are particularly valuable in engineering education: direct work with industrial equipment and structured exposure to functioning production environments. Together, they reduce the gap between academic learning and industrial practice. Industrial robotics is especially useful as a learning platform because it reflects many characteristics of contemporary production systems. It requires logic, precision, sequence control, awareness of safety constraints, and understanding of inputs, outputs, and process dependencies. It is therefore not only a technical tool, but also a medium through which students can engage with the operational logic of the digital economy. When robotics-based learning is combined with observation in a factory environment, students can move beyond isolated technical tasks toward a more comprehensive understanding of how technological systems contribute to organisational value creation. This paper analyses an educational intervention implemented at WSB-NLU in Nowy Sacz, Poland. The intervention combined laboratory classes using an industrial robot with a structured study visit to a manufacturing company. The article interprets this initiative not as an isolated teaching activity, but as a mechanism for managing competency development in engineering education. This perspective situates the case within management and quality sciences, where the strategic design of educational processes, stakeholder alignment, and quality of outcomes are central concerns. The research problem addressed in this paper concerns how higher education institutions can manage the development of competencies required by the digital economy and Industry 4.0. Although technological transformation has changed the expectations placed on engineering graduates, many study programmes still rely on fragmented technical instruction and provide limited exposure to authentic industrial environments. This creates a gap between educational processes and the competency needs of the new economy. The main research question is therefore formulated as follows: How can industrial robotics and university-industry collaboration support the management of Industry 4.0-related competencies in engineering education for the digital economy? To support the analysis, three sub-questions are posed. First, what competencies relevant to Industry 4.0 can be developed through robotics-based experiential learning? Second, how does exposure to real industrial environments influence students' perceptions of professional readiness? Third, what role does university-industry collaboration play in aligning educational outcomes with labour market needs? The contribution of this paper is fourfold. First, it offers a management-oriented interpretation of robotics-based education. Second, it shows how a focused educational intervention can create value for students, institutions, and external partners. Third, it introduces a quality perspective by examining how such interventions enhance the relevance, coherence, and applicability of engineering education in the digital economy. Fourth, it provides a conceptual basis for further doctoral research connecting competency management, higher education quality, and university-industry relations within a single analytical framework.

2. LITERATURE REVIEW

The transition to Industry 4.0 has accelerated the need to transform engineering education alongside technological change. Contemporary production systems are increasingly characterised by automation, digital connectivity, data integration, cyber-physical systems, and intelligent manufacturing. As a result, engineering graduates are expected to possess not only strong technical expertise but also systems thinking, analytical capabilities, adaptability, communication skills, and a comprehensive understanding of production processes. These changing requirements challenge higher education institutions to redesign curricula and learning environments to better prepare graduates for the digital economy.

Previous studies emphasise that engineering education must evolve to meet these emerging demands. For example, Coskun et al. (2019) argue that Industry 4.0 requires substantial changes in curriculum design, laboratory infrastructure, and learning environments. Likewise, Das et al. (2020) highlight the importance of active learning, interdisciplinary education, and stronger links between universities and industry. More recently, Pekarcikova et al. (2025) demonstrate that educational robotics provides an effective platform for developing technical, digital, and process-oriented competencies required in Industry 4.0 and Industry 5.0 environments. Recent review evidence also highlights implementation patterns, pedagogical strategies, and the importance of industry alignment in integrating Industry 4.0 into engineering education (Khan & Mourad, 2025).

Experiential learning has emerged as a key pedagogical approach for developing these competencies. Tembrevilla, et al. (2024) show that practical learning experiences strengthen student engagement, facilitate the application of theoretical knowledge, and foster professional identity. Similarly, Baena et al. (2017) describe learning factories as educational environments that replicate industrial processes and enable students to acquire practical skills in realistic settings. Vila et al. (2017) further demonstrate that project-based collaborative learning enhances Industry 4.0 competencies by integrating technical tasks within authentic manufacturing contexts. Likewise, Vilalta-Perdomo et al. (2022) report that challenge-based learning improves students' understanding of industrial systems by exposing them to real-world problem-solving scenarios.

Competency development has consequently become a central concern in both educational and management research. Kipper et al. (2021) identifies digital literacy, systems thinking, analytical capability, interdisciplinarity, and adaptability as essential competencies for Industry 4.0. From a management perspective, competency development should be viewed as a strategic organisational objective rather than an incidental outcome of teaching. This requires the alignment of curricula, instructional methods, assessment practices, educational infrastructure, and stakeholder expectations to ensure that graduates acquire competencies relevant to rapidly evolving labour market demands.

University-industry collaboration plays a critical role in achieving this alignment. According to Evans et al. (2023), effective collaboration between universities and industry facilitates knowledge exchange, supports digital transformation, and creates mutual value for all stakeholders. Such collaboration may take the form of industrial site visits, practical workshops, guest lectures, internships, equipment sharing, or joint curriculum development. When embedded within educational programmes rather than implemented as isolated initiatives, these activities substantially enhance the authenticity and practical relevance of engineering education.

From the perspective of management and quality sciences, competency-based education and quality management provide complementary theoretical foundations for understanding these developments. Competency-based education emphasises learning outcomes centred on clearly defined professional capabilities rather than content coverage alone (Biggs & Tang 2011). Similarly, quality management in higher education highlights curriculum relevance, stakeholder engagement, continuous improvement, and responsiveness to societal and labour market needs as key determinants of institutional effectiveness (Harvey & Green 1993). Together, these perspectives suggest that integrating industrial robotics with direct industrial experience represents a strategic approach to improving both educational quality and graduate employability.

Despite the growing body of literature, an important research gap remains. Existing studies primarily focus on comprehensive educational reforms, smart factories, or extensive university-industry partnerships. Comparatively little attention has been devoted to targeted educational interventions that can be implemented with relatively limited resources while still generating meaningful educational and managerial outcomes. This study addresses this gap by examining an educational intervention that combines robotics-based laboratory instruction with a structured factory visit as an integrated approach to competency development for Industry 4.0.

2.1. THEORETICAL FRAMEWORK

This study is grounded in four complementary perspectives: competency-based education, the Triple Helix model, stakeholder theory, and quality management in higher education. Together, these perspectives provide a framework for understanding how educational interventions can support competency development while strengthening the relevance and quality of engineering education.

Competency-based education shifts the emphasis from knowledge acquisition to the development of capabilities that graduates are expected to demonstrate in professional practice (Biggs et al. 2011). Within engineering education, this approach encourages the design of learning environments that enable students to apply theoretical knowledge, solve practical problems, understand complex systems, and evaluate the consequences of engineering decisions.

The Triple Helix model views innovation as the outcome of interactions among universities, industry, and government (Etzkowitz & Leydesdorff, 2000). Although this study focuses primarily on university-industry collaboration, the model highlights the broader role of universities as contributors to innovation ecosystems and regional development. By collaborating with industry in curriculum design and practical learning activities, universities enhance graduate preparedness while supporting knowledge transfer and workforce development.

Stakeholder theory further explains the importance of aligning educational provision with labour market expectations. Universities are accountable not only to students and regulatory bodies but also to employers, industry partners, and society more broadly (Freeman, 1984). From a management perspective, educational programmes can be viewed as organisational processes whose quality depends on their ability to meet stakeholder needs while maintaining academic standards and institutional autonomy.

The quality management perspective complements these frameworks by emphasising continuous improvement, stakeholder orientation, process coherence, and outcome relevance as key dimensions of educational quality (Harvey & Green, 1993). Consequently, the effectiveness of higher education should be assessed not only by compliance with institutional standards but also by its capacity to develop competencies that are valued in contemporary professional environments.

Viewed through these theoretical perspectives, the educational intervention analysed in this study represents more than a teaching innovation. Robotics-based laboratory activities support competency development, the industrial study visit strengthens university-industry collaboration, engagement with industrial practice enhances stakeholder alignment, and the integration of both components into a coherent learning experience contributes to educational quality. Together, these elements position the intervention as a strategic approach to competency management within the context of Industry 4.0 and the digital economy.

Table 1. Competency areas supported by the educational intervention

Competency area	Educational trigger	Observed manifestation	Management relevance
Technical interpretation	Robot programming and motion logic	Students connected commands with machine behaviour and process consequences	Supports competence mapping to Industry 4.0 roles
Process awareness	Factory visit and sequence observation	Students recognised relationships between machines, flow, quality and coordination	Improves alignment between curriculum and production reality
Systems thinking	Combined laboratory and industrial exposure	Students linked isolated technical tasks with broader socio-technical systems	Strengthens curriculum integration
Communication and questioning	Interactive observation and guided discussion	Students asked more focused procedural and professional questions	Enhances engagement and reflective learning
Professional orientation	Exposure to departments, roles and industrial expectations	Students better understood how study content relates to work contexts	Supports employability and stakeholder value

Source: Author's elaboration

3. RESEARCH METHODOLOGY

This study adopts a qualitative case study approach to examine how an educational intervention can support competency development and enhance the relevance of engineering education in the context of Industry 4.0. Rather than seeking statistical generalisation, the study aims to generate an in-depth understanding of a context-specific educational process and its implications for competency management and educational quality. A qualitative case study is appropriate because it enables the investigation of complex phenomena within their real-life setting and facilitates process-oriented interpretation (Yin, 2018).

The case was conducted during the 2025/2026 academic year at a private university in southern Poland. This institutional context is particularly relevant because practice-oriented private universities operate in highly competitive environments and are under increasing pressure to align educational provision with labour market expectations and technological change.

The educational intervention comprised two integrated components. The first involved laboratory classes using an industrial robot as part of automation and robotics instruction. The second consisted of a structured study visit to a manufacturing company. These activities were designed as complementary elements of a single learning process, enabling students to connect theoretical knowledge acquired in the laboratory with real industrial practice.

Data were collected through methodological triangulation to enhance the credibility and depth of the analysis (Yin, 2018). Four sources of qualitative evidence were examined: laboratory teaching materials and instructional scenarios, structured classroom observations, documentation and reflective records from the industrial visit, and instructor observations regarding student engagement, participation, and observable learning outcomes. Combining multiple sources of evidence enabled a more comprehensive interpretation of the educational intervention than reliance on a single data source.

The analysis was organised around themes derived from the research questions, including competency development, practical relevance of teaching, student engagement, professional orientation, university-industry collaboration, labour market alignment, and educational quality. These themes were interpreted through the theoretical perspectives of competency management, stakeholder orientation, and quality management in higher education.

As an exploratory study, the research does not seek to quantify competency gains or establish causal relationships. Instead, it identifies mechanisms through which the intervention appears to support competency development and improve the relevance of engineering education. This approach is consistent with qualitative case study methodology, which prioritises analytical insight and theoretical contribution over statistical inference.

The study is guided by four working assumptions. First, integrating industrial robotics into laboratory teaching enhances the practical relevance of engineering education. Second, direct exposure to industrial environments improves students' understanding of engineering practice and professional expectations. Third, combining robotics-based instruction with university-industry collaboration strengthens the alignment between educational outcomes and labour market needs. Fourth, embedding learning activities within authentic technological and organisational contexts enhances the quality and relevance of engineering education.

Several limitations should be acknowledged. The study examines a single institutional case and is based on qualitative observations and interpretive analysis. It does not assess long-term competency development or graduate employability, nor does it compare outcomes across multiple institutions or student cohorts. Nevertheless, the findings provide valuable insights into how relatively small-scale educational interventions can contribute to competency management and curriculum improvement. Future research could extend this work through comparative case studies, student surveys, longitudinal designs, or mixed method approaches to validate and expand the present findings.

4. CASE DESCRIPTION

The educational intervention was implemented at WSB-NLU in Nowy Sącz, Poland, a university that has increasingly emphasised practice-oriented education in fields related to information technology, automation, and modern manufacturing technologies. Within this strategic context, the introduction of industrial robotics was viewed not merely as a teaching innovation but as part of a broader institutional effort to enhance educational quality, curriculum relevance, and responsiveness to labour market needs.

A persistent challenge in engineering education is that students often encounter automation and robotics through simulations, simplified exercises, or theoretical lectures, with limited exposure to real industrial systems. Although these approaches provide an essential conceptual foundation, they frequently fail to capture the complexity of contemporary production environments. The intervention addressed this limitation by integrating robotics-based laboratory instruction with direct exposure to industrial practice.

The first component consisted of laboratory classes using an industrial robot. Students were introduced to robot programming, coordinate systems, motion control, input-output operations, sequence programming, trajectory planning, and basic parameter configuration. Rather than focusing solely on programming techniques, the laboratories were designed to develop an understanding of how control logic translates into physical movement, process execution, and production performance.

From an educational perspective, the laboratory created an environment in which theoretical concepts could be immediately applied and verified. Students observed how modifications to programming commands influenced robot behaviour, reinforcing their understanding of precision, sequencing, safety requirements, and process control. Consequently, the laboratory functioned as a competency-development environment rather than simply a technical demonstration.

The second component involved a structured study visit to a manufacturing company in southern Poland. While the laboratory provided controlled interaction with industrial technology, the factory visit enabled students to observe automation within its organisational context. Participants examined production processes, automation systems, quality control procedures, and coordination between technical and operational functions. This experience demonstrated how engineering decisions contribute to production efficiency, quality assurance, and organisational performance.

Beyond technical observation, the industrial visit broadened students' understanding of engineering practice by illustrating the interaction between technological systems, organisational structures, and managerial processes. It highlighted that automation operates within broader production systems characterised by communication, coordination, quality standards and continuous improvement.

The educational value of the intervention resulted primarily from the integration of both components. Laboratory activities provided opportunities to acquire technical competencies in a controlled environment, whereas the industrial visit contextualised these competencies within authentic production settings. Together, they created a coherent learning sequence that strengthened the connection between theory and practice while enhancing the overall quality and relevance of the educational process.

The case also reflects broader institutional objectives. Universities seeking to strengthen their practical orientation must often balance resource limitations, curriculum requirements, and diverse stakeholder expectations. Consequently, educational innovation depends not only on access to advanced technologies but also on their purposeful integration into programme design. In this respect, the intervention represents a strategic approach to improving engineering education rather than an isolated teaching activity.

5. RESULTS AND DISCUSSION

The intervention produced several educational outcomes relevant to competency management and higher education quality. The most immediate effect was an improvement in students' understanding of technical concepts. Topics that are often perceived as abstract became more accessible once students observed how programming decisions influenced robot movement, sequencing, and process execution. Practical interaction with industrial equipment enabled students to connect theoretical concepts with observable system behaviour, reinforcing the value of experiential learning.

The factory visits further strengthened this understanding by demonstrating that automation is embedded within wider organisational processes. Students observed how production quality, efficiency, safety, and coordination depend on the effective integration of technical systems with organisational practices. This broader perspective encouraged students to interpret engineering decisions not as isolated technical tasks but as contributors to organisational performance.

A second important outcome was increased student engagement. Practical learning environments encouraged students to ask more focused questions, explore alternative solutions, and actively investigate the operation of industrial systems. Exposure to a real manufacturing environment further enhanced motivation by demonstrating the practical relevance of the knowledge acquired during laboratory classes and illustrating potential career pathways.

The intervention also supported students' professional development by strengthening the connection between academic learning and industrial practice. Rather than perceiving engineering subjects as isolated modules, students gained a clearer understanding of how technical competencies are applied within production systems, quality management, and engineering departments. This contributed to a stronger awareness of professional expectations and graduate employability.

The findings further indicate that the intervention supported the development of competencies associated with Industry 4.0. Students demonstrated improved understanding of automated systems, process logic, sequencing, and system interdependencies while also recognising the importance of communication, observation, and analytical reasoning. These outcomes correspond with previous studies emphasising that modern engineering requires a combination of technical, analytical, and transferable competencies.

From a labour market perspective, the intervention improved the alignment between educational outcomes and employer expectations. Rather than replicating workplace conditions, the educational process enabled students to understand the organisational context in which engineering competencies are applied and the professional capabilities increasingly valued by industry.

The intervention also generated institutional benefits. It reinforced the university's practice-oriented profile, strengthened relationships with industrial partners, and enhanced the visibility of engineering programmes. Such initiatives contribute not only to educational improvement but also to institutional competitiveness, stakeholder confidence, and long-term strategic positioning. However, the findings suggest that these benefits depend on meaningful curriculum integration rather than the simple adoption of advanced technologies.

From the perspective of quality management, the intervention illustrates how educational quality can be enhanced through coherent curriculum design, stakeholder engagement and authentic learning experiences. Educational quality extends beyond compliance with formal standards; it also depends on the extent to which learning activities remain relevant, integrated and responsive to labour market needs.

Finally, the case highlights the importance of reinforcement and guided reflection in competency development. Students encountered similar principles in both laboratory and industrial settings, allowing theoretical knowledge to be consolidated across multiple contexts. Structured reflection supported this process by helping students interpret their observations and connect practical experience with conceptual understanding. These findings suggest that practical learning achieves the greatest educational value when accompanied by deliberate pedagogical guidance and opportunities for critical reflection.

Table 2. Management and quality dimensions of the intervention

Dimension	Before intervention	After intervention	Quality implication
Teaching relevance	Predominantly theoretical framing	Higher connection between theory and observable process logic	Improved curricular fitness for purpose
Stakeholder alignment	Limited direct contact with industrial context	Stronger exposure to employer reality and production expectations	Better alignment with external needs
Student engagement	Topic interest varied and remained partly abstract	More focused questions and stronger professional curiosity	Higher educational effectiveness
Institutional positioning	Practice-oriented profile developing	More visible evidence of authentic technology use and cooperation	Strengthened strategic differentiation
Competency coherence	Technical content partly fragmented	Integrated understanding of technical and organisational logic	Greater internal coherence of learning outcomes

Source: Author's elaboration

6. MANAGERIAL IMPLICATIONS

This study contributes to management and quality sciences by conceptualising competency development as a strategic organisational process rather than solely a pedagogical activity. From this perspective, the central challenge for higher education institutions is to design, implement, and evaluate educational processes that respond to evolving stakeholder expectations while maintaining academic standards. The findings demonstrate that industrial robotics and university-industry collaboration can serve as effective managerial mechanisms for achieving this objective (Freeman, 1984; Evans et al., 2023).

First, the intervention highlights the importance of stakeholder-oriented curriculum design. Educational programmes become more relevant when universities actively consider the expectations of students, employers, and society. Such alignment does not compromise academic autonomy; instead, it enhances the practical value of engineering education while preserving its scholarly foundations.

Second, the findings reinforce the role of quality management in higher education. Educational quality extends beyond formal accreditation and administrative procedures to include curriculum coherence, authentic learning experiences, and meaningful connections between theoretical knowledge and professional practice (Harvey & Green, 1993). By integrating laboratory instruction with industrial experience, the intervention strengthened the consistency and relevance of the learning process.

Third, the study demonstrates that meaningful educational innovation does not necessarily require large-scale investments. Even relatively modest initiatives can generate significant educational and organisational benefits when they are strategically designed and embedded within the curriculum. This finding is particularly relevant for institutions operating under financial or infrastructural constraints, where effective educational management depends more on purposeful design than on technological scale.

Fourth, the case illustrates that university-industry collaboration should be viewed as an integral component of educational quality rather than as a promotional or symbolic activity. When industry partnerships directly influence curriculum design and learning experiences, they enhance educational relevance, strengthen stakeholder relationships, and support institutional development.

Fifth, the findings suggest a practical approach to competency governance. Competencies are first identified through labour market requirements and curriculum objectives, then developed through authentic learning activities, reinforced through industrial experience, and consolidated through structured reflection. This sequence demonstrates that competency development can be systematically planned, implemented, and evaluated as part of an institution's quality management strategy.

Finally, the study has implications for internal quality assurance. In addition to conventional indicators such as student satisfaction and course evaluations, quality systems should assess the authenticity of learning activities, the extent of industry engagement, and the alignment between intended learning outcomes and professional practice. Such an approach would provide a more comprehensive assessment of educational effectiveness and graduate preparedness.

Beyond its practical implications, the study offers a conceptual foundation for future research by positioning competency management as a bridge between management, quality assurance, and engineering education. This perspective provides opportunities for further investigation into programme governance, stakeholder management, educational innovation, and institutional adaptation in response to technological change.

6.1. A QUALITY-ORIENTED MODEL OF EDUCATIONAL INTERVENTION

Based on the findings, a quality-oriented model of educational intervention can be proposed. The model comprises five interconnected stages: (1) identification of competency requirements, (2) translation of these requirements into curriculum design, (3) implementation through authentic technological learning, (4) contextualisation through university-industry collaboration, and (5) reflection and competency consolidation. Each stage contributes to both educational quality and competency management.

The first stage involves identifying competencies demanded by the labour market, particularly those associated with Industry 4.0, including automation, robotics, digital technologies, and process-oriented thinking. The second stage translates these requirements into learning objectives, teaching methods, curriculum content, and resource allocation. At this stage, managerial decisions concerning infrastructure, partnerships, and educational planning play a crucial role.

The third stage focuses on authentic technological learning through direct interaction with industrial equipment. In the present study, this was achieved through robotics-based laboratory instruction, allowing students to develop practical competencies in a controlled educational environment. The fourth stage extends this learning through direct exposure to industrial practice. The factory visits enabled students to observe how technological systems operate within organisational processes, thereby strengthening the connection between technical knowledge and professional practice.

The final stage emphasises reflection and competency consolidation. Guided discussion enables students to interpret their experiences, integrate theoretical and practical knowledge, and understand the broader organisational significance of the competencies they have developed.

From a quality management perspective, this model demonstrates that educational effectiveness depends not on isolated innovations but on the coherence of the entire learning process. It also provides a framework for future empirical research, as each stage can be operationalised through competency indicators, curriculum evaluation measures, stakeholder feedback, or quality assessment criteria. Consequently, the model offers a practical foundation for designing, managing, and evaluating educational interventions that support competency development in the context of the digital economy and Industry 4.0.

7. LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

This study has several limitations that should be acknowledged. First, it is based on a single institutional case and, therefore, the findings cannot be generalised to all higher education contexts. Second, the analysis relies on qualitative observations and interpretive evidence rather than standardised measures of competency development or student perceptions. Third, the study captures only one stage of the educational process and does not examine long-term outcomes such as graduate employability, competency retention, or differences across student cohorts. These limitations are consistent with the exploratory nature of qualitative case study research (Yin, 2018).

Despite these limitations, the study provides a foundation for future research. Subsequent studies could incorporate student surveys to assess perceived competency development, professional readiness, and the educational value of robotics-based learning. Developing competency frameworks based on Industry 4.0 requirements would also facilitate systematic comparisons between intended and achieved learning outcomes while strengthening methodological rigour.

Comparative research across universities would further enrich understanding of how similar interventions perform in different institutional settings, engineering disciplines, and forms of university-industry collaboration. Longitudinal studies could examine whether practical industrial exposure influences graduates' employability, adaptability and career development after entering the labour market.

Future research may also develop an integrated framework linking stakeholder expectations, competency management, educational quality and university-industry collaboration. Such a framework would contribute to management and quality sciences by explaining how higher education institutions can strategically design educational processes that respond to technological and labour market change.

8. CONCLUSION

This study examined how industrial robotics and university-industry collaboration can support competency management in engineering education within the context of the digital economy and Industry 4.0. Drawing on a qualitative case study conducted at a private university in southern Poland, the findings demonstrate that integrating robotics-based laboratory instruction with a structured industrial study visit enhances the relevance and quality of the educational process. The intervention strengthened the connection between theoretical knowledge and industrial practice, increased student engagement, improved professional awareness, and supported the development of competencies associated with Industry 4.0. At the institutional level, it reinforced the university's practice-oriented profile and strengthened cooperation with industry partners. More importantly, the findings suggest that competency development should be understood as a strategically managed educational outcome rather than a by-product of traditional teaching. From the perspective of management and quality sciences, the study highlights that educational quality depends on the alignment between curriculum design, stakeholder expectations, authentic learning environments and competency development. In this context, industrial robotics represents more than a technological teaching tool; it serves as a mechanism for enhancing curriculum relevance, supporting university-industry collaboration, and improving the overall quality of engineering education. Overall, the study demonstrates that robotics-based experiential learning, supported by meaningful collaboration with industry, provides a practical and scalable approach to preparing engineering graduates for the digital economy. By integrating competency management, stakeholder orientation, and quality enhancement within a single analytical framework, the paper contributes to the growing literature on higher education management and offers a foundation for future research on educational innovation in the era of Industry 4.0.

REFERENCES

Baena, F., Guarin, A., Mora, J., Sauza, J., & Retat, S. (2017). Learning factory: The path to Industry 4.0. *Procedia Manufacturing,* 9, 73-80. https://doi.org/10.1016/j.promfg.2017.04.022

Biggs, J., & Tang, C. (2011). Teaching for quality learning at university: What the student does (4th ed.). *Open University Press*. https://books.google.pl/books/about/Teaching_For_Quality_Learning_At_Univers.html?id=XhjRBrDAESkC&redir_esc=y

Coşkun, S., Kayıkcı, Y., & Gençay, E. (2019). Adapting engineering education to Industry 4.0 vision. *Technologies*, 7(1), 10. https://doi.org/10.3390/technologies7010010

Das, S., Kleinke, D., & Pistrui, D. (2020). Reimagining engineering education: Does Industry 4.0 need Education 4.0? In Proceedings of the ASEE Virtual Annual Conference. https://www.researchgate.net/publication/339983822_Reimagining_Engineering_Education_Does_Industry_40_Need_Education_40

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: From National Systems and Mode 2 to a Triple Helix of university-industry-government relations. *Research Policy*, 29(2), 109-123. https://doi.org/10.1016/S0048-7333(99)00055-4

Evans, N., Miklosik, A., & Du, J. T. (2023). University-industry collaboration as a driver of digital transformation: Types, benefits and enablers. *Heliyon*, 9(10), e21017. https://doi.org/10.1016/j.heliyon.2023.e21017

Freeman, R. E. (1984). Strategic management: A stakeholder approach. *Pitman*. https://books.google.pl/books?id=NpmA_qEiOpkC&printsec=frontcover&hl=pl&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false

Harvey, L., & Green, D. (1993). Defining quality. Assessment & Evaluation in Higher Education, 18(1), 9-34. https://doi.org/10.1080/0260293930180102

Khan, S. H., & Mourad, A. H. I. (2025). Integrating Industry 4.0 in engineering education: Implementation patterns, pedagogical strategies, and industry alignment. *Cogent Education*, 12(1), 2588010. https://doi.org/10.1080/2331186X.2025.2588010

Kipper, L. M., Iepsen, S., Dal Forno, A. J., Frozza, R., Furstenau, L., Agnes, J., & Cossul, D. (2021). Scientific mapping to identify competencies required by Industry 4.0. *Technology in Society*, 64, 101454. https://doi.org/10.1016/j.techsoc.2020.101454

Pekarcikova, M., Trebuna, P., Kliment, M., Kronova, J., & Matiscsak, M. (2025). Educational robotics for Industry 4.0 and 5.0 with Wlkata Mirobot in laboratory process modelling. *Machines*, 13(9), 753. https://doi.org/10.3390/machines13090753

Tembrevilla, G., Phillion, A., & Zeadin, M. (2024). Experiential learning in engineering education: A systematic literature review. *Journal of Engineering Education*, 113(1), 195-218. https://doi.org/10.1002/jee.20575

Vila, C., Ugarte, D., Ríos, J., & Abellán, J. V. (2017). Project-based collaborative engineering learning to develop Industry 4.0 skills within a PLM framework. *Procedia Manufacturing*, 13, 1269-1276. https://doi.org/10.1016/j.promfg.2017.09.050

Vilalta-Perdomo, E., Michel-Villarreal, R., & Thierry-Aguilera, R. (2022). Integrating Industry 4.0 in Higher Education Using Challenge-Based Learning: An Intervention in Operations Management. *Education Sciences*, 12(10), 663. https://doi.org/10.3390/educsci12100663

Yin, R. K. (2018). Case study research and applications: Design and methods (6th ed.). SAGE Publications. https://ebooks.umu.ac.ug/librarian/books-file/Case%20Study%20Research%20and%20Applications.pdf