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A Micro-Credential Pathway to Safer and More Reliable Engineering for Industry 4.0

Nor Fadzilah Abdullah^a, Asma Abu-Samah^a, Sahar Heidary^a, Ili Hazwani Zulkifli^a, Rozita Ibrahim^b, Nasrudin Subhi^c, Rosdiadee Nordin^a, Mehran Behjati^d, and Marco Zennaro^e

Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia^a, Pusat Citra Universiti (PCU), Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia^b, Faculty of Social Sciences and Humanities, University Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia^c, Department of Engineering, School of Engineering and Technology, Sunway University, 47500 Bandar Sunway, Malaysia^d, The Abdus Salam International Centre for Theoretical Physics (ICTP), Str. Costiera, 11, 34151 Trieste, Italy^e.
Corresponding Author's Email: fadzilah.abdullah@ukm.edu.my

ABSTRACT

BACKGROUND & CONTEXT

Industry 4.0 transforms industries with intelligent machines, automation, and data-driven decisions. This shift demands a new approach to workforce development. Personnel must blend technical depth with strong soft skills. However, traditional education struggles to keep pace, creating a skills gap.

PURPOSE OR GOAL

Micro-credentials with focused learning units offer a remedy. They provide targeted, flexible training for rapid upskilling. With it, workers can be empowered to adapt to evolving Industry 4.0 demands. Unfortunately, most current micro-credentials isolate hard or soft skills. Therefore, this work introduces a micro-credential framework known as Boosting Engineering Safety and Reliability for IR 4.0: Integrated Approach of Soft and Hard Skills (BESTARI 4.0).

APPROACH OR METHODOLOGY

BESTARI 4.0 links macro drivers of Industry 4.0 competency to an integrated curriculum. It translates cyber-physical automation, pervasive data, and human-machine collaboration into modular learning. The modules unite resource-constrained TinyML engineering techniques with critical thinking, communication, and team problem-solving. The BESTARI 4.0 micro-credential is delivered on an open online platform with clear objectives, video labs, annotated notes, quizzes, and real-world safety cases.

OUTCOMES

The ultimate outcome is the development of a proficient workforce in deploying machine learning solutions that enhance productivity. Simultaneously, safety and reliability within next-generation industrial settings can also be improved.

CONCLUSIONS

By integrating soft and hard skills, BESTARI 4.0 builds durable competence rather than short-lived certifications. It offers a scalable pathway for Malaysia and the wider region to operationalize Industry 4.0 safely and productively.

KEYWORDS

Micro-credential; engineering education; machine learning; soft skills; lifelong learning.

Introduction

Industry 4.0 has changed the engineering and manufacturing fields by combining cyber-physical systems, the Internet of Things (IoT), and advanced data analytics (Konstantinidis, 2022). Increased automation, real-time data exchange, and smart systems characterize this new industrial era, enhancing efficiency, productivity, and customization capabilities. Conventional curricula often fail to provide students with the essential skills to navigate the intricacies of Industry 4.0 (Wolff, 2019). A key element of Industry 4.0 is Machine learning (ML). It is a technology that empowers computers to learn from data, allowing them to improve their skills over time. Training algorithms on large datasets enables them to recognize patterns, make informed decisions, and tackle complex tasks across various fields such as healthcare, finance, and transportation (Reddi, 2021). Applications of ML span various fields, including image recognition, natural language processing, recommendation systems, medical diagnosis, financial forecasting, and autonomous vehicles. According to (Kotti, 2022), ML can address engineering challenges, such as fault detection and anomaly identification, that traditional algorithms and methods struggle to solve. ML can significantly reduce manual efforts such as automatic program repair, code suggestion, defect prediction, malware detection, and feature location, with high-accuracy results.

Engineering education must adapt to prepare students for the technologically sophisticated and interconnected settings of Industry 4.0 adequately. Additionally, an effective engineering team must exhibit diverse competencies, including soft skills and hard skills. According to the Accreditation Policy and Procedure Manual, Accreditation Board of Engineering and Technology (ABET, 2021), a key criterion for assessing engineering education is preparing students for engineering practice. ABET emphasizes the importance of communication, teamwork, and understanding the social, political, economic, and global implications of engineering work. However, traditional engineering curricula often focus more on technical skills than soft skills (Anwar, 2022). Hence, there is a pressing need for educational programs that combine technical proficiency with soft skills to produce well-rounded engineers capable of thriving in this dynamic landscape. Figure 1 illustrates the key soft skills for Industry 4.0 engineers.

Micro-credentials have emerged as a transformative element in modern education, offering flexible and focused pathways to acquire specific skills and knowledge (Weko, 2020). Unlike traditional degrees, these specialized certificates enable learners to rapidly acquire proficiency in targeted areas and stay aligned with technological innovations and industry standards (McGreal, 2022). This approach is particularly relevant in engineering, where new technologies and methods continuously emerge (Rajabalee, 2023). Micro-credential programs have become an increasingly popular tool for addressing specific skill gaps in various industries, including engineering. Several institutions have successfully implemented these programs to enhance both academic learning and industry readiness. For instance, Purdue University offers Data Science Micro-Credentials, providing valuable workplace skills through specialized courses in areas like data visualization, machine learning, and statistical analysis (King, 2023). Similarly, the University of New South Wales' Digital Grid Futures Institute offers industry-aligned micro-credentials in smart grid technologies, equipping students with practical skills for the energy sector and demonstrating the effectiveness of micro-credentials in addressing industry needs and workforce development (Hopkins, 2024). Beyond institutional programs, popular online platforms like Coursera, edX, Udemy, LinkedIn Learning, and FutureLearn offer diverse micro-credential courses, providing flexible, accessible certifications across various fields. These credentials enable professionals to upskill or reskill, meeting evolving industry demands and fostering lifelong learning for enhanced career competitiveness.

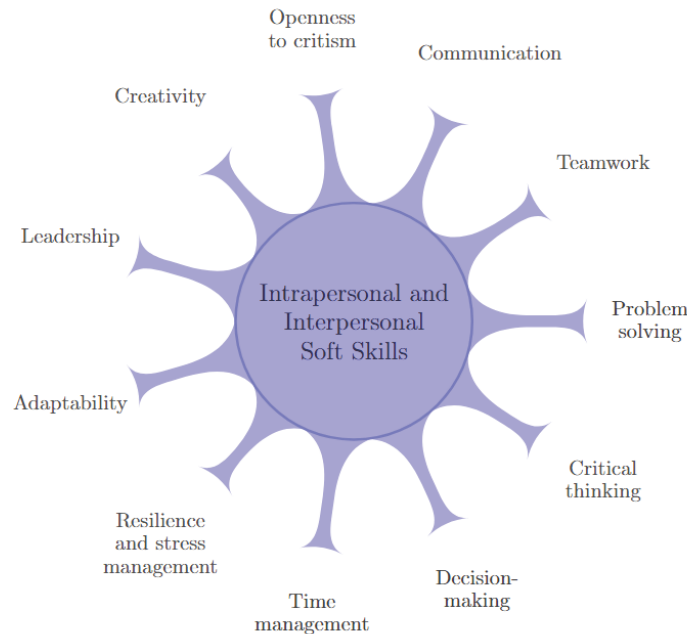


Figure 1: Key soft skills for Industry 4.0 engineers

This paper emphasizes the importance of integrating technical and soft skills into engineering education to address the challenges of Industry 4.0. By designing a micro-credential course focused on TinyML, a subfield of machine learning (ML) designed for low-power devices with limited resources, engineering safety and reliability can be enhanced. This course aims to provide students with hands-on experience using ML technologies to solve real-world problems, alongside a focus on essential soft skills such as communication, teamwork, and problem-solving. The novelty of this paper is summarised as follows:

1. Conduct a thorough analysis of the skills gap in Industry 4.0 and design a micro-credential module to address these needs.
2. Propose a novel practical framework that outlines how machine learning can be integrated with soft skills for enhanced engineering safety and reliability.
3. Develop a micro-credential curriculum that can be tailored to different sectors within Industry 4.0.
4. Discuss strategies for promoting continuous learning and skill development beyond completing micro-credential programs.

Machine Learning for Engineering Safety and Reliability

The Fourth Industrial Revolution, also referred to as IR 4.0 or Industry 4.0, is a fundamental shift in how we live, work, and interact. Its defining characteristic is the deep integration of information and communication technologies (ICT) across industrial sectors. Building upon the computer-based manufacturing systems of Industry 3.0, Industry 4.0 introduces network connectivity and digital twin technology, creating interconnected and virtualized production environments (Mathur, 2021).

The rapid technological advancements driving previous industrial revolutions dramatically reshaped manufacturing and service industries. The subsequent convergence of IT, services, and manufacturing further amplified productivity gains (Farsi, 2019). Today, organizations face the challenge of integrating key Industry 4.0 technologies, including the Industrial Internet of Things (IIoT), Cyber-Physical Systems (CPS), robotics, cybersecurity, data analytics, and additive manufacturing (Lee, 2019). While Industry 4.0 offers the potential for significant productivity increases by fundamentally reshaping manufacturing and production processes

(Rauch, 2020), its successful implementation often requires clear performance metrics and a structured roadmap. By integrating IoT and CPS, Industry 4.0 transforms traditional enterprises into smart factories.

In Industry 4.0, safety and reliability are not merely desirable attributes but are fundamental to its successful implementation and sustained operation. While the convergence of advanced technologies like artificial intelligence, robotics, and IoT offers unprecedented opportunities for innovation and productivity, it also introduces new complexities and potential hazards (Baro-Tijerina, 2021). Ensuring the secure and reliable operation of these interconnected systems is crucial for preventing accidents, protecting lives, and maintaining business continuity. Across engineering workplaces, risk emerges wherever energy, motion, chemicals, electricity, and structural loads interact with people and equipment. Recent reviews show that effective control blends inherently safe design with procedural safeguards and continuous monitoring to manage both acute accidents and chronic degradation of equipment over time (da Rosa, 2021).

In mechanical and manufacturing settings, common hazards include moving machinery, pinch points, robots or collaborative robots (cobots), pressurized systems, and ergonomics. Reliability losses often begin with bearings and seal wear, misalignment, poor lubrication, vibration-induced fatigue. Evidence links human-robot collaboration to new safety considerations, underscoring the need for guarding, lockout/tagout, and condition-based maintenance. Meanwhile, bearings remain a classic weak link; modern fault detection relies on time-frequency analysis and learning methods for early warning (Pauliková, 2021; Wu, 2022).

In electrical and electronic work, key hazards are electric shock and arc flash, while reliability concerns center on thermal overstress, insulation breakdown, electromagnetic compatibility or electromagnetic interference (EMC/EMI), and solder-joint fatigue. The mechanisms and mitigation of lithium-ion battery thermal runaway, incident-energy reduction strategies for arc flash, and fatigue phenomena that degrade electronics over time, supporting practices such as de-energization, selective coordination, thermal design, and robust interconnects (Tran, 2022; Nowak, 2021; Goerl, 2019).

In the chemical process domain, prominent hazards are flammable or toxic releases, corrosives, reaction runaways, dust explosions, and high-pressure equipment. Reliability challenges include corrosion and erosion, valve and seal failures, sensor drift, and safety instrumented system (SIS) performance. Recent reviews highlight industrial dust-explosion mechanisms, the persistence of corrosion under insulation (CUI) in oil and gas assets, evolving practice for SIS life-cycle implementation, and progress in valve health diagnostics. These motivates hazard and operability study (HAZOP), layers of protection analysis (LOPA), targeted safety integrity level (SIL) protection layers, risk-based inspection (RBI), and modern monitoring (Eckhoff, 2021; Cao, 2022; Steinhauser, 2019; Zhang, 2023).

Meanwhile, for civil fields such as construction and infrastructure, frequent hazards include work at height, crane and lifting operations, excavation or trench collapse, and temporary-works instability. Reliability issues span concrete defects, reinforcement corrosion, ground settlement or slope failure, and water ingress. Persistent causal factors are supervision gaps, inadequate method statements, and poor protection (Wang, 2025; Akboga Kale, 2021; Buitrago, 2020; Angst, 2020). Table 1 summarizes the engineering safety and reliability concerns across various engineering fields.

With today's data streams from vibration, thermography, supervisory control and data acquisition (SCADA), structural health monitoring (SHM) and video feeds, machine learning (ML) has become essential to move from reactive fixes to predictive and prescriptive safety and reliability. Evidence shows embedding ML alongside established standards helps anticipate failures, prioritize interventions, and continuously reduce risk (Carvalho, 2019; Fang, 2020; Cha, 2024).

Within Industry 4.0 paradigm, Tiny Machine Learning (TinyML) emerges as a crucial enabler, bringing intelligence to resource-constrained devices like microcontrollers. TinyML empowers these devices to perform on-device analysis, unlocking real-time data processing, predictive maintenance, and optimized production processes at the edge, without the need for constant cloud connectivity (Abadade, 2023). This localized, cloud-independent processing reduces latency, conserves bandwidth, enhances privacy, and enables operation in disconnected environments, crucial for many industrial applications. TinyML facilitates a wide range of Industry 4.0 applications, including predictive maintenance (Ooko, 2024), smart agriculture (Kalyani, 2021), healthcare, smart manufacturing, and smart cities.

Table 1: Summary on Engineering Safety & Reliability Concerns at the Workplace in Various Engineering Fields

Engineering field	Safety & Reliability Concerns
Mechanical & Manufacturing	<i>Safety hazards:</i> Rotating or moving machines; pinch or entanglement points; robots and collaborative robots; hot work such as welding or cutting; pressurized systems; forklifts and factory traffic; excessive noise and poor workstation design. <i>Reliability risks:</i> Worn bearings and seals; shaft misalignment; metal fatigue and cracking; lack of lubrication; vibration-related faults; leaks in pneumatic or hydraulic lines.
Electrical & Electronic	<i>Safety hazards:</i> Electric shock and arc flash; battery fires or “thermal runaway”; static electricity; working on powered equipment; radio-frequency exposure; poor isolation and grounding. <i>Reliability risks:</i> Overheating because parts are pushed too hard; insulation breakdown; electrical interference between devices; cracked solder joints or loose connectors; power quality problems that cause unexpected shutdowns.
Chemical	<i>Safety hazards:</i> Releases of flammable or toxic materials; corrosive chemicals; uncontrolled (runaway) reactions; dust explosions; confined spaces; high-pressure pipes and vessels. <i>Reliability risks:</i> Corrosion and erosion of equipment; fouling and blockages; valves and safety relief valves failing to open; pump or seal leaks; instruments drifting out of calibration; safety systems not triggering when needed.
Civil	<i>Safety hazards:</i> Working at height; lifting and crane operations; excavation or trench collapse; failure of temporary structures such as scaffolds or formwork; working near live traffic; dust, noise and silica exposure; contact with underground or overhead utilities. <i>Reliability risks:</i> Instability of permanent or temporary structures; defects from poor concrete curing; corrosion of reinforcing steel; ground settlement or slope failure; water ingress and inadequate drainage.

Micro-credential for Boosting Engineering Safety and Reliability for IR 4.0: Integrated Approach of Soft and Hard Skills (BESTARI 4.0)

In this section, we present a new micro-credential module termed as BESTARI 4.0 (Boosting Engineering Safety and Reliability for IR4.0: Integrated Approach of Soft and Hard Skills). It integrates soft skills and technical (hard) skills to enhance engineering safety and reliability for Industry 4.0 (IR4.0). The BESTARI 4.0 module was developed through an iterative process

that involved several Focus Group Discussions (FGDs) and a pilot workshop, ensuring its alignment with industry needs and educational goals.

Three FGDs have been conducted in 2023, involving engineers from our industry partner, IX Telecom, as well as final year undergraduate students from the Department of Electrical and Electronic Engineering programme, Universiti Kebangsaan Malaysia (UKM). Each FGD lasted 90 minutes and involving participants with 1 to 2 years of working experience. The first FGD (FGD1) conducted on 3rd February 2023 (7 participants) highlighted the acquisition of leadership and communication skills, with challenges in managing multicultural clients, long working hours, and tight deadlines. FGD2 conducted on 1st November 2023 (10 students) emphasized teamwork, leadership, and communication skills, while addressing difficulties such as time management, generation gaps, and gender-related issues. Lastly, FGD3 conducted on 13th December 2023 (6 participants) focused on leadership, communication, and English proficiency, with challenges like technical limitations, work-life balance, and gender barriers. All groups acknowledged the impact of these challenges on their well-being and stressed the need for enhancing skills like time management, decision-making, and critical thinking.

The pilot workshop is intended to serve as formative trial in a low-stakes environment to verify instructional flow, gauge learner engagement, and collect qualitative feedback on both the TinyML technical labs and the embedded soft-skill exercises before scaling BESTARI 4.0 more broadly. The pilot workshop involve a selection of 25 participants, which rely mainly on observational data and participant reflections. The pilot workshop included an opening session, an icebreaker activity, and the delivery of each course lesson. Several practical exercises, simulations, and case studies were provided and complemented with allocated time for Q&A and discussion after each session. During the workshop, students are evaluated on their ability to implement TinyML solutions in engineering projects, as well as their proficiency in soft skills. The use of project-based assessments, where students work on real-world engineering challenges, allows for a practical evaluation of both technical and interpersonal abilities.

Based on insights from the FGDs and pilot workshop, the BESTARI 4.0 micro-credential is categorised into two micro-courses, namely (i) TinyML for Engineering Safety, and (ii) Soft Skill for Responsible Engineers. For each micro-courses, there are 11 micro-lessons. For an open-access hosting, the BESTARI 4.0 micro-credential are hosted on the IEEE's (Institute of Electrical and Electronics Engineers) Circuits and Systems Society Micro-learning platform (CASSMiLe). The module not only included lecture videos and slides, but also a recording of an expert forum between leading academics and industry partners, as well as real-world case study scenes and an animation video. Several assessment methods of each micro-lesson were incorporated into the modules. Each micro-lesson is incorporated with MCQ (multiple choice questions), thought-provoking forum questions, and additional resources to dig further. The structure of the BESTARI 4.0 micro-courses is shown in Table 2.

Table 2: Structure of BESTARI 4.0 Micro-credential Modules

Micro-course title	Micro-lesson titles
TinyML for Engineering Safety (Technical skill)	1. Why Machine Learning (ML) for Engineering Safety?
	2. Motivation on the Needs of Soft and Hard Skills for Engineering Safety
	3. Introduction to ML
	4. Development of ML models
	5. Intro to Deep Learning (DL)
	6. Comparison of available platforms for DL
	7. ML in Tiny Embedded system

	8. TinyML With Edge Impulse
	9. Setting Up Edge Impulse Project
	10. Building Edge Impulse Models
	11. Ensuring Engineering Safety with TinyML
Soft Skills for Responsible Engineers (Soft skill)	1. The Power of Soft Skills for Engineers
	2. Introduction to Intrapersonal Skills: Soft Skill for Responsible Engineering
	3. Emotional Intelligence: A Key to Personal and Professional Success
	4. Coping with Workplace Stressors: Strategies for a Healthy Work Environment
	5. Building Resilience and Adaptability: Navigating Challenges in the Workplace
	6. Introduction to Interpersonal Skills: Building Effective Connections
	7. Mastering Effective Communication: Building Strong Connections
	8. Navigating Decisions and Solving Problems with Ease
	9. The Art of Team Collaboration
	10. Unleash Your Leadership Brilliance: Navigating the Path to Effective Leadership
	11. Ensuring Engineering Safety with Soft skills

The development and implementation of micro-credential modules like BESTARI 4.0 have revealed several best practices. First, it is essential to maintain a strong alignment between the course content and industry needs. This requires continuous engagement with industry stakeholders to ensure that the skills being taught are relevant to current and future market demands. Another key lesson is the importance of flexibility in course design. Given the rapid pace of technological change, it is vital that micro-credential programs are adaptable and regularly updated to incorporate new trends and tools.

Conclusion

BESTARI 4.0 addresses a critical gap in engineering education by offering a micro-credential framework that integrates technical TinyML competencies with essential soft skills for Industry 4.0. Whereas most programmes treat hard and soft skills separately, BESTARI 4.0 combines them to prepare engineers for safety-critical, highly automated environments. Focus-group discussions with practicing engineers and students ground the curriculum in real-world needs, underscoring the growing importance of communication, leadership, and adaptability alongside machine-learning proficiency. Notably, the framework is among the first to embed TinyML, a low-cost ML tool that is vital for edge computing, into a micro-credential format. The findings in this work extend the literature on micro-credentials by showing that experiential, project-based modules can bridge the academia-industry skills gap. Delivered on the IEEE CASS platform, BESTARI 4.0 provides scalable, flexible training that cultivates both technical expertise and soft-skill competence. This integrated approach establishes a new benchmark for micro-credential design and offers a replicable model for institutions seeking to develop a workforce aligned with Industry 4.0 demands.

References

- Abadade, Y., Temouden, A., Bamoumen, H., Benamar, N., Chtouki, Y., & Hafid, A. S. (2023). A comprehensive survey on TinyML. *IEEE Access*, 11: 96892-96922. <https://doi.org/10.1109/ACCESS.2023.3294111>
- Accreditation Board of Engineering and Technology (ABET) (2021). *Accreditation Policy and Procedure Manual*. Accessed at <https://www.abet.org/wp-content/uploads/2021/01/A001-21-22-Accreditation-Policy-and-Procedure-Manual.pdf> on 30 September 2024.
- Akboga Kale, Ö., Ural, S., & Çakır, C. (2021). Characteristic analysis and prevention strategy of trench collapse accidents in the U.S. (1995–2020). *Ingeniería de Construcción*, 36(3): 617–636. <https://doi.org/10.7764/rdlc.20.3.617>
- Angst, U., et al. (2020). Corrosion of steel in carbonated concrete. *RILEM Technical Letters*, 5: 85–100. <https://doi.org/10.21809/rilemtechlett.2020.127>
- Anwar, S. (2022). *Essential skills for the 21st-century engineer*. Murdoch University. <https://researchportal.murdoch.edu.au/esploro/outputs/991005593869407891>
- Baro-Tijerina, M., Piña-Monarez, MR. Arredondo, RDM. (2021). Reliability Engineering in Industry 4.0. In G. a Vargas-Solar (Ed.), *Critical factors in Industry 4.0. A Multidisciplinary Perspective* (pp. 73–94). Mexico: Instituto de Ingeniería y Tecnología. <http://cathi.uacj.mx/20.500.11961/19240>
- Buitrago, M., et al. (2020). Avoiding failures during building construction using feedback from structural safety reports. *Engineering Structures*, 206: 110–122. <https://doi.org/10.1016/j.engstruct.2019.109906>
- Cao, Q., et al. (2022). A review of corrosion under insulation in the oil and gas industry. *Metals*, 12(4), 561. <https://doi.org/10.3390/met12040561>
- Carvalho, T. P., Soares, F. A. A. M. N., Vita, R., Francisco, R. P., Basto, J. P., & Alcalá, S. G. (2019). A systematic literature review of machine learning methods applied to predictive maintenance. *Computers & Industrial Engineering*, 137, 106024. <https://doi.org/10.1016/j.cie.2019.106024>
- Cha, Y.-J., et al. (2024). Deep learning-based structural health monitoring: A comprehensive review. *Automation in Construction*, 159, 105074. <https://doi.org/10.1016/j.autcon.2024.105328>
- da Rosa, A. C. F., Lapasini Leal, G. C., Galdamez, E. V. C., & de Souza, R. C. T. (2021). Risk management in occupational safety: A systematic mapping. *Work*, 70(1), 147-166. <https://doi.org/10.3233/WOR-213561>
- Eckhoff, R. K. (2021). Industrial dust explosions: A brief review. *Applied Sciences*, 11(4), 1669. <https://doi.org/10.3390/app11041669>
- Fang, W., Love, P. E. D., Luo, H., et al. (2020). Computer vision applications in construction safety assurance. *Automation in Construction*, 110, 103013. <https://doi.org/10.1016/j.autcon.2019.103013>
- Farsi, MA. Zio, E. (2019). Industry 4.0: some challenges and opportunities for reliability engineering. *International Journal of Reliability, Risk and Safety: Theory and Application* 2(1): 23-34. <https://doi.org/10.30699/ijrrs.2.1.4>
- Goerl, R., Villa, P., Vargas, F. L., Marcon, C. A., Medina, N. H., Added, N., & Guazzelli, M. A. (2019). Combined ionizing radiation & electromagnetic interference test procedure to achieve reliable integrated circuits. *Microelectronics Reliability*, 100, 113341. <https://doi.org/10.1016/j.microrel.2019.06.033>
- Hopkins, C., & Moller, F. (2024). Institute of Coding in Wales Digital Skills Bootcamps–Micro-Credentials: A Pilot Project. *Proceedings of the 8th Conference on Computing Education Practice* (pp. 21-24). Durhan, United Kingdom. <https://doi.org/10.1145/3633053.3633055>
- IEEE CASS Microlearning. Accessed at <https://ml.ieee-cas.org/> on 3 September 2025.
- Kalyani, Y., & Collier, R. (2021). A systematic survey on the role of cloud, fog, and edge computing combination in smart agriculture. *Sensors*, 21(17), 5922. <https://doi.org/10.3390/s21175922>
- Konstantinidis, F. K., Myrillas, N., Mouroutsos, S. G., Koulouriotis, D., & Gasteratos, A. (2022). Assessment of industry 4.0 for modern manufacturing ecosystem: A systematic survey of surveys. *Machines*, 10(9), 746: 1-26. <https://doi.org/10.3390/machines10090746>
- Kotti, Z., Galanopoulou, R., & Spinellis, D. (2023). Machine learning for software engineering: A tertiary study. *ACM Computing Surveys*, 55(12): 1-39. <https://doi.org/10.1145/3572905>
- King, I., & Lee, W. I. (2023). *A Decade of MOOCs and Beyond*. Springer eBooks. Cham, Switzerland: Springer. <https://doi.org/10.1007/978-3-031-15241-2>
- Lee, J., Cameron, I., & Hassall, M. (2019). Improving process safety: What roles for Digitalization and Industry 4.0? *Process Safety and Environmental Protection*, 132: 325-339. <https://doi.org/10.1016/j.psep.2019.10.021>
- Mathur, A., Dabas, A., & Sharma, N. (2022). Evolution from Industry 1.0 to Industry 5.0. *4th International Conference on Advances in Computing, Communication Control and Networking (ICAC3N)* (pp. 1390-1394). <https://doi.org/10.1109/ICAC3N56670.2022.10074274>

- McGreal, R., Mackintosh, W., Cox, G., & Olcott Jr, D. (2022). Bridging the Gap: Micro-credentials for Development. *International Review of Research in Open and Distributed Learning*, 23(3): 288-302. <https://doi.org/10.19173/irrodl.v23i3.6696>
- Nowak, K., et al. (2021). The possibilities to reduce arc-flash exposure with thyristor-based eliminators. *Energies*, 14(7), 1927. <https://www.mdpi.com/1996-1073/14/7/1927>
- Ooko, S. O., & Karume, S. M. (2024). Application of tiny machine learning in predicative maintenance in industries. *Journal of Computing Theories and Applications*, 2(1), 131-150. <https://doi.org/10.62411/jcta.10929>
- Pauliková, A., et al. (2021). Analysis of the impact of human–cobot collaboration on workers' safety and health. *International Journal of Environmental Research and Public Health*, 18(4), 1927. <https://www.mdpi.com/1660-4601/18/4/1927>
- Rajabalee, Y. (2023). The implementation of micro-credentials in formal and informal learning: A systematic literature review. *International Journal of Learning and Teaching*, 9(4), 328-336. <https://doi.org/10.18178/ijlt.9.4.328-336>
- Rauch, E., Linder, C., & Dallasega, P. (2020). Anthropocentric perspective of production before and within Industry 4.0. *Computers & Industrial Engineering*, 139, 105644: 1-15. <https://doi.org/10.1016/j.cie.2019.01.018>
- Reddi, V. J., Plancher, B., Kennedy, S., Moroney, L., Warden, P., Suzuki, L., ... & Tingley, D. (2022). Widening Access to Applied Machine Learning with TinyML. *Harvard Data Science Review*, 4(1). <https://doi.org/10.1162/99608f92.762d171a>
- Steinhauser, E. P., et al. (2019). Addressing the challenges of implementing safety-instrumented systems. *Process Safety and Environmental Protection*, 123, 1–14. <https://doi.org/10.1016/j.jlp.2018.11.019>
- Tran, M. K., et al. (2022). A review of lithium-ion battery thermal runaway modeling and prognosis. *Processes*, 10(6), 1192. <https://www.mdpi.com/2227-9717/10/6/1192>
- Wang, Y., et al. (2025). Analysis of the causes of falling accidents on building construction sites. *Buildings*, 15(9), 1412. <https://doi.org/10.3390/buildings15091412>
- Weko, T., Kato, S., & Galán-Muros, V. (2020). *The emergence of alternative credentials*. OECD Publishing. <https://doi.org/10.1787/b741f39e-en>
- Wolff, K. E., & Booyesen, M. J. (2019). The smart engineering curriculum. *Proceedings of 8th Research in Engineering Education Symposium (REES)* (pp. 1-9). Cape Town, South Africa. <https://doi.org/10.31224/osf.io/nbh6c>
- Wu, G., Chen, J., & Wang, S. (2022). A review on rolling bearing fault signal detection and diagnosis. *Sensors*, 22(21), 8081. <https://pmc.ncbi.nlm.nih.gov/articles/PMC9654419/>
- Zhang, S., et al. (2023). A review of valve health diagnosis and assessment techniques. *Measurement*, 226, 114339. <https://doi.org/10.1016/j.engfailanal.2023.107581>

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