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Micro-credential for Industry 4.0: engineering safety and reliability with integrated machine learning and soft skills

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ABSTRACT

The Fourth Industrial Revolution [Industry 4.0 (IR4.0)] transforms industries with intelligent machines, automation and data-driven decision-making. This paradigm shift demands a workforce equipped with both advanced technical know-how and strong soft skills. Traditional curriculum struggles to keep up, creating a skills gap. Targeted micro-credentials can close this gap by offering flexible, bite-sized training aligned to real-world needs. Unlike existing micro-credentials that focus on either hard or soft skills in isolation, this work presents Boosting Engineering Safety and Reliability for IR 4.0: Integrated Approach of Soft and Hard Skills (BESTARI 4.0), as a practical framework that links the macro-drivers of the IR4.0 competency requirements, such as cyber-physical automation, pervasive data and human-machine collaboration. It translates those requirements into micro-credential modules that weave together resource-constrained tiny machine learning-based engineering techniques with essential soft-skill development, such as critical thinking, communication and team problem-solving. The BESTARI 4.0 micro-credential, delivered on an open online platform, specifies clear learning objectives and experiential tasks, such as video labs, annotated notes, formative quizzes and real-world safety case studies. The ultimate outcome is the development of a proficient workforce in deploying machine learning solutions that enhance productivity while simultaneously improving safety and reliability within next-generation industrial settings.

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1. Introduction

Industry 4.0 (IR4.0) has changed the engineering and manufacturing fields by combining cyber-physical systems, the Internet of Things (IoT) and advanced data analytics (Konstantinidis et al., 2022). Increased automation, real-time data exchange and smart systems characterise this new industrial era, enhancing efficiency, productivity and customisation capabilities.

Industrial 4.0 demands that engineers pair technical expertise with human-centric abilities that machines cannot replicate (Jones et al., 2022; Wilkens, 2020). Social and interpersonal skills, such as effective communication, collaboration, strategic forecasting, self-organisation, creativity, decision-making, leadership and adaptability, give professionals a decisive edge (Bennett et al., 2025; Boyacı et al., 2024; de Weerd et al., 2024; Wilkens, 2020). Labor-market data confirm that even technical roles increasingly reward these non-cognitive competencies (S. H. Kim & Kwon, 2024). Jobs requiring advanced social skills have expanded faster than those driven mainly by mathematical ability

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(Hirudayaraj et al., 2021), underscoring that twenty-first-century careers rely on heightened interpersonal proficiency (Rios et al., 2020). Hodgman (2018) stresses that employers highly value work-related skills, internships and the critical thinking of graduates, highlighting the need for educational programs to better prepare students for the job market. However, conventional curricula often focus more on technical skills than soft skills (Anwar, 2022) and are not updated with the essential skills to navigate the technologically sophisticated intricacies of IR4.0 (Wolff & Booyesen, 2019).

Micro-credentials have emerged as a transformative element in modern education, offering flexible and focused pathways to acquire specific skills and knowledge (Kato et al., 2020; Kipper et al., 2021). By targeting specific competencies, they let learners keep pace with rapid technological change and evolving industry standards (McGreal et al., 2022). This approach is particularly relevant in engineering, where new technologies and methods continuously emerge (Rajabalee, 2023). Integrated into engineering curricula, micro-credentials support lifelong learning, close skill gaps and prepare graduates for the demands of IR4.0.

This paper emphasises the importance of integrating technical and soft skills into engineering education to address the challenges of IR4.0. By designing a micro-credential course focused on tiny machine learning (TinyML), a subfield of machine learning (ML) designed for low-power devices with limited resources, engineering safety and reliability can be enhanced.

The novelty of this paper is summarised as follows:

1. Conduct a thorough analysis of the skills gap in IR4.0 and design a micro-credential module that can be tailored to different sectors.
2. Develop a novel micro-credential framework, known as Boosting Engineering Safety and Reliability for IR 4.0: Integrated Approach of Soft and Hard Skills (BESTARI 4.0), with practical modules that integrate ML techniques with soft skills for enhanced engineering safety and reliability.
3. Discuss strategies for promoting continuous learning and skill development beyond completing micro-credential programs.

The rest of the paper is structured as follows. [Section 2](#) presents an overview of micro-credentials in engineering education, including a discussion on the various types of micro-credentials, case studies of successful micro-credential programs, as well as potential challenges and solutions for adoption. [Section 3](#) delves into the linkage between IR4.0, ML and engineering safety. Meanwhile, [Section 4](#) presents our proposed micro-credential program to address the needs for IR4.0 towards engineering safety and reliability. Finally, [Section 5](#) concludes the paper. [Figure 1](#) shows the structure of the paper.

2. Micro-credentials in engineering education

Accreditation Policy and Procedure Manual, Accreditation Board of Engineering and Technology (ABET) (2021) stated that a key criterion for assessing engineering education is preparing students for real-world practice. ABET emphasises the importance of communication, teamwork and understanding the social, political, economic and global implications of engineering work.

Micro-credentials offer one way to bridge the skills gap. Defined by short, competency-based study units (Oliver, 2019), they target specific domains such as coding, project management, healthcare, finance or soft skills such as communication and leadership. Credentials may be digital badges, certificates, micro-masters or nanodegrees, each validated through formal assessments that map to professional standards or authenticated by reputable authorities (Kurzweil, 2020; Rossiter & Tynan, 2019). Their value spans all life stages, supporting upskilling, reskilling and lifelong learning (Oliver, 2021; Tamoliune et al., 2023).

Students gain job-ready skills quickly and inexpensively, improving employability and career mobility (Anderson et al., 2020; McGreal et al., 2022). Employers report that micro-credentialed staff raise service quality and revenue (Thi Ngoc Ha et al., 2024), while industry-aligned content helps close technology-related skills gaps (Ward et al., 2023). For universities, micro-credentials strengthen industry ties, attract enrolments and enhance cost-effectiveness (Dayton et al., 2018). Educators also benefit through pedagogical innovation and sustained engagement with industry practice (Bianco et al., 2023). Embedding

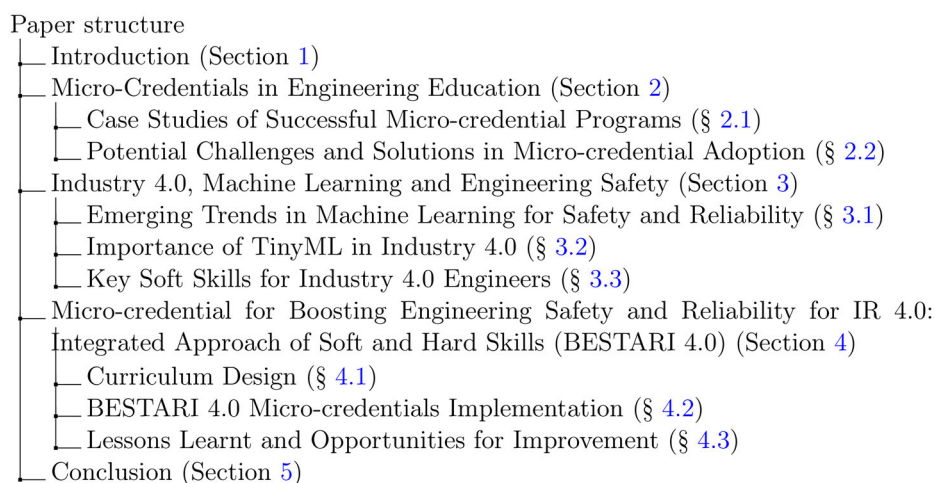


Figure 1. Organisation of this paper.

micro-credentials within degrees boosts student motivation and performance (Alt, 2023; Woods & Woods, 2023).

Effective micro-credentials align tightly with workplace needs and engage self-directed learners (Al-Rahmi et al., 2021; Gish-Lieberman et al., 2021). Adoption depends on provider reputation, meaningful learner–educator interaction and visible peer endorsements (Jung & Lee, 2018; Virani et al., 2023). Institutions known for innovation are quickest to integrate micro-credentials as flexible complements to traditional programs (Pirkkalainen et al., 2023). When designed around high-quality standards and authentic assessments (Peacock et al., 2020), micro-credentials become a powerful tool for modern, demand-driven education.

2.1. Case studies of successful micro-credential programs

Micro-credential programs have become an increasingly popular tool for addressing specific skill gaps in various industries, including engineering. Although interest has surged, micro-credentials build on long-standing formats like massive open online courses (MOOCs) and short courses (Olcott, 2022).

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 specialised courses in areas like data visualisation, ML and statistical analysis (King & Lee, 2022). 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 & Moller, 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. Tables 1 and 2 present several existing micro-credential modules focused on developing engineers' soft and hard skills.

2.2. Potential challenges and solutions in micro-credential adoption

The rise of MOOCs and micro-credentials is viewed either as a temporary trend or a fundamental shift in education (Moore, 2022). After an early burst of enthusiasm—intensified by the COVID-19 pandemic's abrupt move to online education, interest waned when universities began commercialising these offerings (Billsberry & Alony, 2024). To remain viable, micro-credentials must overcome several hurdles. Critics question the quality of micro-credentials, calling many courses 'superficial and lightweight' (Gilliat-Ray, 2020), and their materials 'confusing' (Cowley et al., 2021). Outcomes vary, where experienced learners

Table 1. Existing micro-credential modules focusing on soft skills.

Module title	Key area	Key soft skills	Platform	Access type	Duration
Creative Thinking: Techniques and Tools for Success (MCS1)	IT, engineering	Creative thinking, problem solving, creativity	Coursera	Open	19 h
Becoming an Effective Leader (MCS4)	Engineering	Leadership, management, empathy, leadership styles, human capital	edX	Paid (free audit)	10 weeks
Soft Skills: The 11 Essential Career Soft Skills (MCS8)	Engineering	Personal and career development	Udemy	Paid	34 h
Mastering Communications as a Leader (MCS12)	Engineering	Leadership, communication	LinkedIn Learning	Paid	2 h
Soft Skills for Navigating Global Challenges (MCS11)	Education	Leadership, collaboration and teamwork, emotional intelligence	FutureLearn	Paid	3 weeks
People and Soft Skills for Professional and Personal Success Specialisation (MCS2)	Engineering	Negotiation, conflict resolution	Coursera	Paid	4 weeks
Soft Skills: Present with Purpose (MCS5)	Engineering, business	Intercultural communication, global awareness	edX	Paid	5 weeks
Soft Skills: Develop Interpersonal Skills (MCS6)	Business	Asserting influence, different communication styles, listening skills	edX	Open	1 week
Soft Skills: Solve Problems Creative & Critical Thinking (MCS7)	Business	Critical and creative thinking, solving problem	edX	Open	1 week
Soft Skills Masterclass—5 in 1, Communication, Leadership (MCS9)	Education	Personal transformation, personal development	Udemy	Paid	31 h
Soft Skills Life Coach Certification (6-courses-in-1) (MCS10)	Education	Soft skills, communication, business	Udemy	Paid	12 h
Developing Interpersonal Skills (MCS3)	Education	Communication, listening skills, people management, organisational conflict	Coursera	Free	3 h

finish quickly, whereas novices struggle (Peacock et al., 2020). Time pressures, cost and unreliable Internet further limit uptake (Cowie & Sakui, 2021).

A notable concern is the uneven recognition of micro-credentials. Employers and academic institutions often doubt credentials that lack common standards (Van der Hijden & Martin, 2023). Some fear that micro-credentials promote a ‘gig-economy’ view of education by reducing learning to job-specific skills only (Wheelahan & Moodie, 2022). Aligning micro-credentials with frameworks such as the European Qualifications Framework and co-designing courses with industry can bolster credibility (McGreal et al., 2022).

Quality assurance and engagement also matter. Without oversight, course standards fluctuate and regional or technological gaps curb access (Young et al., 2019). Partnering with trusted institutions, ensuring mobile-friendly content and issuing recognised certificates can help. Identity checks, plagiarism screening and gamified tasks strengthen integrity and motivation (Ahmat et al., 2021).

Table 2. Existing micro-credential modules combining hard and soft skills.

Module title	Key hard skill	Key soft skills	Platform	Access type	Duration
Introduction to Embedded Machine Learning (MCI1)	ML, embedded system design, computer programming	Project management, creative thinking, problem solving	Coursera	Free	3 weeks, 4–6 h/week
Computer Vision with Embedded Machine Learning (MCI2)	Computer programming, Python programming, ML, microcontroller, embedded system development	Project management, creative thinking, problem solving	Coursera	Free	30 h
HarvardX's TinyML Professional Certificate (MCI3)	Fundamentals of ML, theory and applications of microcontrollers	Critical thinking, decision-making	edX	Paid	4 months
HarvardX: MLOps for Scaling TinyML (MCI4)	Automation, ML	Project management, creative thinking, problem solving	edX	Free	7 weeks
Deploying TinyML (MCI5)	ML, deep learning (DL), embedded systems, computer vision	Project management, creative thinking, problem solving	edX	Free	5 weeks
Machine Learning Foundation (MCI6)	AI, ML	Project management, creative thinking, problem solving	Institute of Applied Technology	Paid	6–8 weeks
TinyML with Wio Terminal (MCI7)	ML, hardware, IT, software	Project management, creative thinking, problem solving	Udemy	Paid	3 h
5 Real-Time Use Cases using Machine Learning (MCI8)	ML, IT, software	Project management, creative thinking, problem solving	Udemy	Paid	5 h
Fundamentals to Become a Machine Learning (MCI9)	ML, Python	Project management, creative thinking, problem solving	LinkedIn Learning	Paid	11 h
Getting Started with AI and Machine Learning (MCI10)	AI, ML	Project management, creative thinking, problem solving	LinkedIn Learning	Paid	10 h

Tackling these issues demands coordination among accreditors, educators and employers. Shared frameworks, jointly developed curricula, and rigorous assessments tied to workforce needs can enhance trust. Added learner support—mentoring, progress tracking, structured peer interactions—should lift completion rates. When standardisation, quality and engagement are addressed, micro-credentials can bridge skills gaps, foster lifelong learning and complement traditional programmes, thereby supporting workforce development (Miller & Jorre de St Jorre, 2024; Oliver, 2021). Table 3 summarises the challenges and possible solutions for micro-credential adoption.

3. IR4.0, ML and engineering safety

The Fourth Industrial Revolution, also referred to as IR 4.0 or Industry 4.0, deeply embeds information and communication technologies in manufacturing, extending the computer-based automation of Industry 3.0 with network connectivity and digital-twin capabilities (George & George, 2020). Earlier revolutions similarly transformed industry—steam power (Industry 1.0), electricity and assembly lines (Industry 2.0) and computerised production (Industry 3.0) to yield major productivity gains (Farsi & Zio, 2019). IR4.0 carries this trajectory forward through industrial Internet of Things (IIoT), cyber-physical systems, robotics, cybersecurity, analytics and additive manufacturing, creating smart factories that demand clear performance metrics and roadmaps (Lee et al., 2019; Rauch et al., 2020).

Looking ahead, Industry 5.0 emphasises human–machine collaboration built upon IR4.0's automation and data foundations (Bosovska et al., 2022). Key enablers include artificial intelligence/machine learning (AI/ML), advanced computing and manufacturing, ubiquitous connectivity and sustainable, resilient

Table 3. Summary of challenges and possible solutions for micro-credential adoption.

Description	Challenges	Solutions
Commitment/integrity	• Lack of discipline • Academic dishonesty	• Progress tracking • Employ proctoring tools
Informal learning source perception	• Not equivalent to traditional certifications • Limited integration	• Accredited institutions • Align course contents
Materials endorsement/control	• Lack alignment with learners' expectations • Inconsistent teaching quality	• Update course materials regularly • Set clear guidelines
Platform availability	• Inaccessible on diverse devices • High subscription costs	• Develop mobile-friendly platforms • Financial aid or freemium access
Certificate issuance	• Ambiguity in certificate validation and authenticity • Lack of credibility with unrecognised providers	• Use digital badges

production—shift workplaces towards proactive, data-driven strategies (Muhuri et al., 2019). Four grand challenges for Industry 5.0 are (Panetto et al., 2019):

- Cyber-Physical Production System based Manufacturing Plant Control
- Resilient digital manufacturing networks, collaborative control for IR4.0 and cyber-physical supply chains
- Cyber-physical System-of-Systems interoperability
- Interdependent networked systems and data analytics for decision support

Figure 2 illustrates the progression from Industry 1.0 to 5.0. Meanwhile, Figure 3 summarises the key enabling technologies for IR 5.0.

3.1. Emerging trends in ML for safety and reliability

ML enables computers to learn from large datasets, recognise patterns and make data-driven decisions across domains, such as image analysis, language understanding, recommender systems, medicine, finance and autonomous transport (Reddi et al., 2021).

According to Kotti et al. (2023), ML in software engineering eases traditionally labour-intensive tasks, such as automatic program repair, defect prediction, code suggestion, malware detection and feature location. The study emphasises cleaner data pipelines, incremental learning and better industry data-sharing to widen adoption.

IR4.0's cyber-physical factories raise unprecedented safety and reliability demands, where system failures can cascade quickly through tightly coupled, AI-driven processes (Baro-Tijerina et al., 2021). Predictive-maintenance studies confirm that ML algorithms, from supervised learners to anomaly detectors, can anticipate equipment breakdowns, prevent accidents, protect lives and minimise downtime when tuned to the plant's data characteristics (Ooko & Karume, 2024; Silvestrin et al., 2019).

Therefore, reliability engineering has evolved from static analysis to continuous performance prediction and optimisation of interconnected smart devices. This also introduces new failure modes and risk interdependencies (Farsi & Zio, 2019). Practical safeguards now include IoT-ready personal protective equipment (PPE) sensors, automated high-risk task handling and cloud platforms that integrate safety data, training and compliance dashboards. Building information modelling extends these benefits to construction by enabling virtual hazard identification before ground is broken (Júnior et al., 2021). Table 4 explores potential challenges and opportunities in maintaining workplace safety and reliability within this evolving landscape.

IR4.0 is likewise reshaping engineering education. Smart labs, learning analytics and on-demand micro-credentials provide agile, industry-aligned upskilling compared with lengthy traditional degrees (Alangari, 2024; Gregg et al., 2022; Neaga, 2019). AI-driven platforms now personalise learning pathways, embedding micro-credentials at the core of lifelong learning strategies for both workers and employers (Shanahan & Organ, 2022). Their role in continuous reskilling, especially for the blended technical and soft-skill profiles that IR4.0 demands, has been widely documented (Batool et al., 2023).

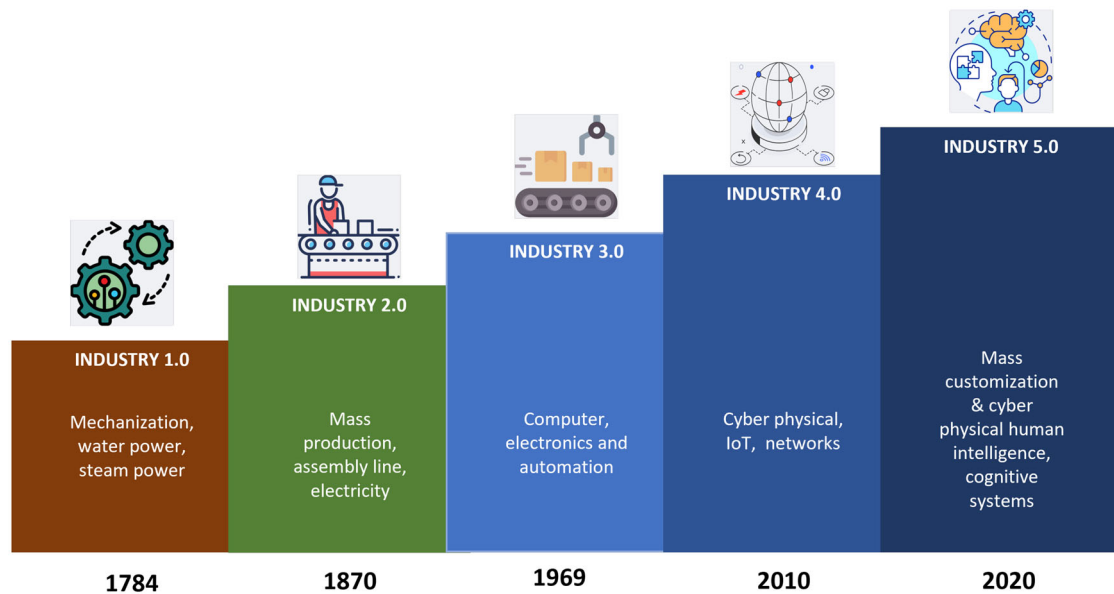


Figure 2. Industrial revolutions through the years from IR1.0 to IR5.0.

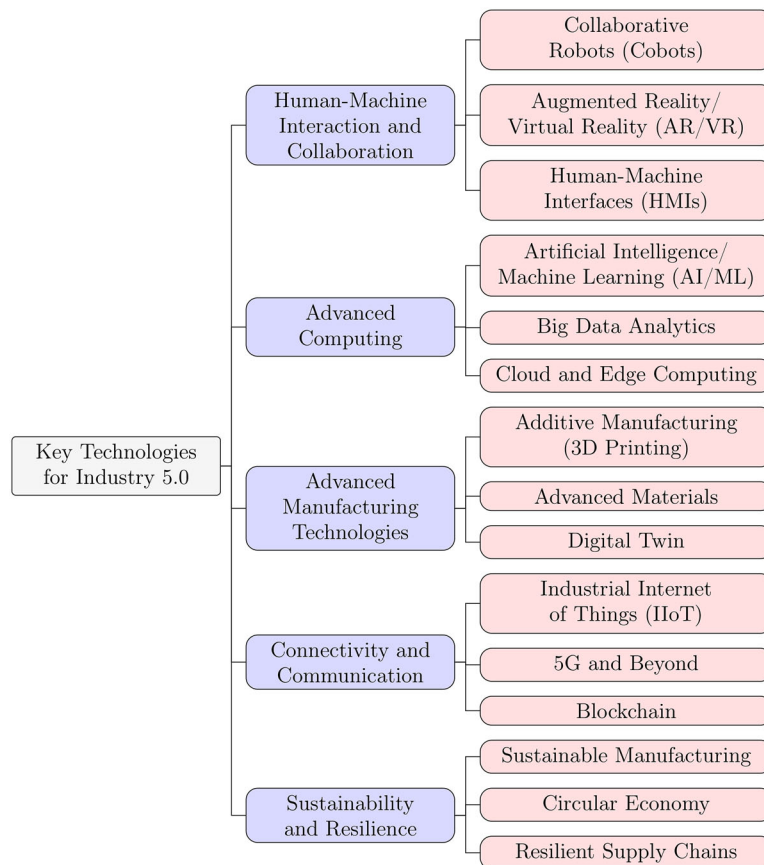


Figure 3. Key technological enhancements for Industry 5.0.

3.2. Importance of TinyML in IR4.0

Tiny machine learning (TinyML) brings AI inference to resource-constrained microcontrollers, enabling real-time analytics, predictive maintenance and process optimisation directly at the industrial edge, without continual cloud access (Abadade et al., 2023). This local execution lowers latency, saves bandwidth, protects data privacy and supports disconnected operation, which are key requirements for many IR4.0

Table 4. Challenges and opportunities in maintaining safety and reliability at the workplace.

Challenges	Description	Opportunities
Evolving regulatory standards	Regulatory bodies constantly update safety standards due to new threats and technological advancements. Thus, businesses must adapt quickly.	• Staying informed about the latest regulations • Implementing and maintaining compliance with rapidly changing standards • Possibility to reduce costs and operational disruptions
Technological integration risks	Increased reliance on technology brings risks like cyber threats and system malfunctions.	• Ensuring the security and reliability of technological systems • Mitigating the impact of cyberattacks and data breaches • Maintaining system uptime and preventing operational disruptions
Human error and behavioural risks	Misjudgements, lapses in concentration, and non-compliance with safety protocols by employees pose significant risks.	• Training and educating employees on safety procedures • Promoting a strong safety culture • Implementing effective safety monitoring and enforcement mechanisms
Environmental hazards	Exposure to toxic substances, extreme weather, etc., can create hazardous working conditions.	• Identifying and assessing potential environmental hazards • Implementing appropriate safety measures (PPE, emergency response) • Mitigating the impact of environmental events
Ergonomic and workplace stress	Poor ergonomics and high stress levels can negatively impact employee health and productivity.	• Designing ergonomic workstations and implementing ergonomic practices • Promoting stress management techniques and creating a supportive work environment • Addressing workplace factors contributing to stress

use cases (Dutta & Bharali, 2021). TinyML has facilitated a wide range of IR4.0 applications, including machine-health monitoring (Ooko & Karume, 2024), smart agriculture (Kalyani & Collier, 2021), healthcare devices (E. Kim et al., 2023), advanced manufacturing lines and smart-city sensors.

Developing and deploying TinyML solutions involves a structured process: identifying relevant use cases, selecting appropriate frameworks, preparing and curating data, training and optimising models for resource constraints, converting models for TinyML deployment, integrating with target devices and leveraging edge computing paradigms. Effective model deployment is made possible via TensorFlow Lite, a condensed version of TensorFlow designed for mobile and embedded devices. Keras Micro makes model creation easier by providing a streamlined framework designed especially for microcontrollers. Effective neural network (NN) inference on edge devices is ensured by Arm NN, which is optimised for Arm-based processors. Interoperability is facilitated by the flexible, cross-platform engine that ONNX Runtime offers, which is compatible with a range of ML models (Reddi et al., 2021). MicroPython provides a lightweight Python implementation for programming, enabling developers to efficiently operate microcontrollers. Specialised platforms like the cloud-based Edge Impulse streamline this process, offering an end-to-end solution for creating and implementing TinyML models.

Meeting IR4.0 demand for TinyML talent requires targeted upskilling. Micro-credentials deliver concise training on model optimisation, IoT integration and edge deployment. Platforms such as Edge Impulse align their tutorials with these credentials, giving learners job-ready skills without a full degree (Karras et al., 2024). Modular, gamified micro-credentials also promote lifelong learning in emerging areas, such as federated learning, energy-aware algorithms and other advances that will further extend TinyML's reach (Richert et al., 2023). By embedding intelligence at the edge and democratising AI education, TinyML strengthens productivity, safety and inclusivity across next-generation industrial environments.

3.3. Key soft skills for IR4.0 engineers

Soft skills encompass both interpersonal and intrapersonal abilities to support effective interaction, reflection and decision-making. They have become indispensable complements to technical expertise in IR4.0 settings (Munir, 2022; Polaková et al., 2023). Listening, critical thinking, clear communication and

concise knowledge summarisation underpin every engineering activity, yet traditional programmes still struggle to embed these competencies systematically (Caeiro-Rodríguez et al., 2021; Teresa et al., 2019). The result is a skills gap that limits productivity and innovation. Soft skills encompass the ability to interact with others effectively (Munir, 2022).

In modern factories and smart infrastructures, engineers must collaborate across disciplines, manage time and lead diverse teams while coping with rapid technological change and stringent safety demands (Choudhary et al., 2022; Jelonek et al., 2020). Employers therefore prioritise candidates who demonstrate strong soft-skill portfolios, viewing them as signals of adaptability, lifelong learning mind-sets and alignment with sustainability goals (Caeiro-Rodríguez et al., 2021; Ibrahim & Abiddin, 2024).

Key intrapersonal attributes, such as self-awareness, resilience and self-management, help engineers regulate stress and navigate uncertainty in highly automated, AI-driven environments (Manhães et al., 2021). Equally vital are interpersonal skills, such as collaborative problem-solving, leadership, and the ability to translate complex technical ideas to non-specialists (Madonna et al., 2019; Munir, 2022). Such capabilities reduce errors, improve safety and foster reliable human-machine collaboration in cyber-physical systems (Kipper et al., 2021).

Creative problem-solving and cross-functional teamwork further support innovation and risk mitigation, ensuring projects meet rigorous safety and efficiency targets (Nuralievna, 2023; Zhou & Zheng, 2022). Industry now expects engineers to pair technical ingenuity with business acumen and cultural fluency, reinforcing the need for curricula that integrate leadership and professional skills (Donald & Jamieson, 2023).

Embedding these competencies can be achieved through micro-credential programmes that combine targeted soft-skill training with emerging technology certifications, giving professionals flexible pathways to practise and demonstrate mastery (Caeiro-Rodríguez et al., 2021). When delivered alongside ML and automation modules, such credentials empower engineers to deploy cutting-edge solutions without compromising safety or reliability, which are core outcomes for any IR4.0 enterprise. Figure 4 highlights key soft skills for IR4.0 engineers.

4. Micro-credential for BESTARI 4.0

In this section, we present a new micro-credential module termed BESTARI 4.0. It is a practical micro-credential framework that integrates soft skills and technical (hard) skills to enhance engineering safety and reliability for IR4.0. The BESTARI 4.0 module was developed through an iterative process that involved focus group discussions (FGDs) and a pilot workshop, ensuring its alignment with industry needs and educational goals.

4.1. Curriculum design

4.1.1. FGDs

The FGDs were conducted to address identified gaps in existing engineering modules and to integrate essential soft skills into the curriculum. This qualitative research method explored participants' experiences and opinions, facilitated by a moderator using an interview protocol comprising open-ended questions aligned with the study objectives. Interviews were audio-recorded, transcribed verbatim and analysed thematically to extract meaningful insights.

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). Further details on the FGDs are shown in Table 5. Each FGD lasted 90 min and involving participants with 1–2 years of experience. The first FGD (FGD1) conducted on 3 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 1 November 2023 (10 students) emphasised teamwork, leadership and communication skills, while addressing difficulties such as time management, generation gaps and gender-related issues. Lastly, FGD3 conducted on 13 December 2023 (6 participants) focused on leadership, communication and English proficiency, with challenges like technical limitations, work-life balance

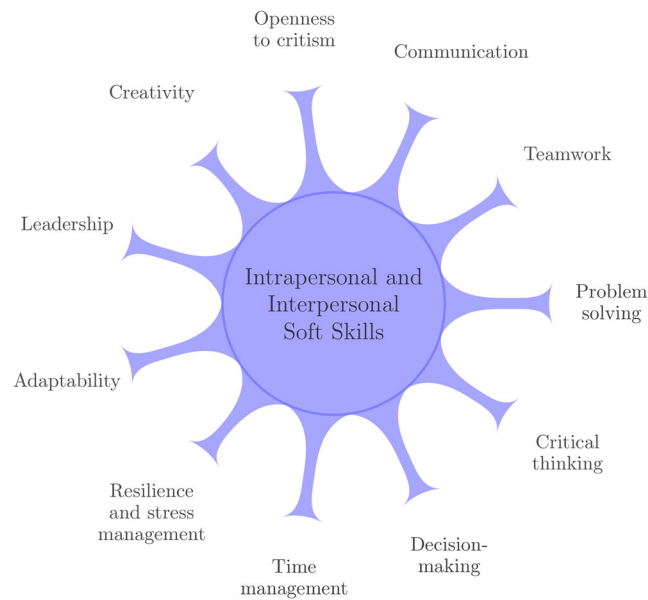


Figure 4. Key soft skills for IR4.0 engineers.

Table 5. Key findings from FGDs.

Description	FGD1	FGD2	FGD3
Date	3 Feb 2023	1 Nov 2023	13 Dec 2023
Duration	90 min	90 min	90 min
Participants	IX Telecom engineers	UKM Undergraduate Engineering Program final year students	IX Telecom engineers
No. of participants	7	10	6
Gender	4 male, 3 female	8 male, 2 female	2 male, 4 female
Work experience	1–2 years	<1 year	1–2 years
Key findings	- Skills acquired: Leadership and communication through on-the-job training. - Challenges: managing multicultural clients and long working hours. - Stressors: Deadlines causing stress. - Skill needs: Time management and effective client communication.	- Skills acquired: Leadership, teamwork, and communication during internships. - Challenges: Time management, generation gaps, handling criticism, and gender issues. - Stressors: Deadlines causing stress. - Skill needs: Critical thinking, negotiation, problem-solving, and setting boundaries.	- Skills acquired: Leadership, communication, and English proficiency from work training. - Challenges: Limited technical experience, gender barriers, and work-life balance issues. - Stressors: Long hours and tight deadlines. - Skill needs: Time management, decision-making, and mastering English for clients.

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.

During the FGDs, participants discussed the following questions:

1. The soft skills they had already acquired or mastered, such as leadership and communication.
2. The challenges they faced related to these skills, including managing diverse clients, meeting deadlines and addressing workplace dynamics.
3. How these challenges impacted their well-being, with stress being a common concern.
4. The soft skills they believed should be included to enhance their competency, such as time management, negotiation and advanced communication.

In FGD1, participants highlighted the importance of leadership and communication skills acquired through on-the-job training and interaction with senior staffs. They emphasised challenges like dealing with clients from multicultural and international backgrounds and managing long or shift work hours. Stress before deadlines was a common concern, impacting their overall well-being. To enhance their

competency, participants suggested focusing on communication with clients, time management and understanding workplace demands.

In FGD2, students recognised the significance of leadership, teamwork and communication skills gained during university and internships. They faced challenges such as time management, gender issues, generation gaps and handling criticism positively. Poor guidance and learning to express emotions were also notable issues. Stress before deadlines was a recurring theme. Skills like critical thinking, negotiation, financial management and learning to set boundaries were considered essential for professional growth.

Meanwhile, participants of FGD3 demonstrated expertise in leadership and communication, particularly during university and work training. Challenges included limited technical experience, gender-related obstacles and language barriers when communicating with clients. Work-life balance and meeting deadlines under demanding schedules were significant stressors. To improve competency, they emphasised mastering English, time management and decision-making skills for addressing client concerns and managing workloads efficiently.

The FGDs revealed the critical importance of soft skills in engineering workplaces and career development. Participants identified several challenges faced by engineers, including stress management, collaboration in multicultural teams, working across different time zones and addressing gender and intergenerational dynamics. These challenges underscored the need to develop key soft skills to navigate complex workplace environments effectively.

The discussions highlighted the necessity of enhancing intrapersonal skills such as emotional intelligence, stress management, resilience and adaptability. Similarly, interpersonal skills like communication, decision-making, problem-solving, team collaboration and leadership were emphasised as essential for professional success. These findings were validated by comparing the results of the FGDs with existing literature on soft skills in engineering. This comparison establishes the core skills that will form the basis of the module.

4.1.2. Pilot workshop

After the completion of the initial micro-credential module, the next step is conducting a pilot workshop to test its suitability, practicality and relevance. The pilot workshops are intended to serve as formative trials, 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. Therefore, note that the findings from this workshop are indicative rather than rigorously empirical. Results are interpreted as design pointers for improvement to the final micro-credentials module, not as statistically generalisable evidence of learning impact. The audience of this pilot workshop consists of lecturers and instructors from two main disciplines, namely Electronic Engineering and Communication Systems, because they are expected to acquire knowledge and skills in the domain of embedded systems and ML.

The pilot workshop included an opening session, an icebreaker activity and the delivery of each course lesson, all of which encouraged active participation and engagement from the participants. 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 like communication. 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. This workshop also aimed to gather feedback on each subtopic's content and all assessments provided, preparing for validated and reliable content that can benefit others before it is made public on the open online micro-credential platform.

Insights from FGDs and a pilot workshop have shaped this module to empower future engineers to improve safety and reliability across disciplines. Thus, the resulting micro-credentials course modules emphasise experiential learning and real-world TinyML applications.



Figure 5. IEEE CASS BOK.

4.2. BESTARI 4.0 micro-credentials implementation

The BESTARI 4.0 micro-credential is categorised into two micro-courses, namely (i) TinyML for Engineering Safety and (ii) Soft Skills for Responsible Engineers. For each micro-course, there are 11 micro-lessons. For open-access hosting, the BESTARI 4.0 micro-credentials are hosted on the Institute of Electrical and Electronics Engineers' (IEEE) Circuits and Systems Society (CASS) Micro-learning (MiLe) platform (IEEE CASS Microlearning, [n.d.](#)). There are 14 IEEE CASS committees, which represent the body of knowledge (BOK) associated with the society, as seen in [Figure 5](#). For the BESTARI 4.0 micro-credentials, three BOK has been chosen for the award of badges, namely (i) Neural Systems and Applications, (ii) Multimedia Systems and Applications and (iii) Circuits and Systems Education and Outreach. The structure of the BESTARI 4.0 micro-courses and assigned BOK is shown in [Table 6](#). 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.

Assessment and validation are critical components of any micro-credential program. Selvaratnam (2023) highlighted the need for clear success metrics to ensure the relevancy and contemporary nature of micro-credentials in a virtual setting. Establishing a clear and transparent assessment rubric that is aligned with industry needs ensures that the micro-credential carries weight in the job market (Tamoliune et al., 2023). Therefore, for BESTARI 4.0, several assessments of each micro-lesson understanding were incorporated into the modules. Each micro-lesson is incorporated with multiple choice questions, thought-provoking forum questions and additional resources to dig further.

As a summary, 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 IR4.0. Whereas most programmes treat hard and soft skills separately, BESTARI 4.0 combines them to prepare engineers for safety-critical, highly automated environments. FGDs with practicing engineers and students ground the curriculum in real-world needs, underscoring the growing importance of communication, leadership and adaptability alongside ML 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.

Table 6. BESTARI 4.0 micro-credential framework.

Micro-course	No.	Micro-lesson title	Main contents	Learning time	BOK
TinyML for Engineering Safety	1	Why ML for Engineering Safety?	- Engineering safety issues to be solved using ML - Benefits of using for engineering safety in IR4.0 - Challenges of using ML for engineering safety - Tips on using ML as a tool for engineering safety	12 min	Neural systems and applications
	2	Motivation on the Needs of Soft and Hard Skills for Engineering Safety	- Hard skills in Engineering Safety in IR 4.0 - Soft skills in Engineering Safety in IR 4.0 - Interplay of hard and soft skills in IR 4.0	13 min	Neural systems and applications
	3	Introduction to ML	- Why ML for engineers? - Types of ML (supervised, unsupervised, and reinforcement learning)	14.5 min	Neural systems and applications
	4	Development of ML models	- Preprocessing: Data collection, preprocessing, and deployment - Learning phase: Model training, model evaluation	8 min	Neural systems and applications
TinyML for Engineering Safety	5	Intro to DL	- Intro to NN and DL - Example of applications using DL	16.5 min	Neural systems and applications
	6	Comparison of available platforms for DL	Variety of DL frameworks and platforms (such as Colab, Pandas, Numpy, TensorFlow and Edge Impulse, including their history, design principles, and main features)	16 min	Neural systems and applications
	7	ML in Tiny Embedded system	- Benefits of combining ML with 'Tiny' embedded system - TinyML open education	18.5 min	Multimedia systems and applications
TinyML for Engineering Safety	8	TinyML With Edge Impulse	- Overview on edge impulse - Model building steps and evaluation metrics	18.5 min	Multimedia systems and applications
	9	Setting Up Edge Impulse Project	- Setting up edge impulse project - Creating datasets (generate from accelerometer, gyro, phone, others sensors) and preprocessing (data cleaning, feature selection and extraction)	15 min	Multimedia systems and applications
	10	Building Edge Impulse Models	- Model evaluation and improvement - Converting model to TensorFlow Lite	16.5 min	Multimedia systems and applications
Soft Skills for Responsible Engineers	11	Ensuring Engineering Safety with TinyML	- Technical skills case study scenarios - Expert forum discussion	43 min	Multimedia systems and applications
	1	The Power of Soft Skills for Engineers	- What are soft skills? - Why soft skills matter at the workplace? - How do soft skills enhance engineering safety and reliability? - How can this module help you?	17.5 min	Circuits and systems education and outreach
	2	Introduction to Intrapersonal Skills: Soft Skill for Responsible Engineering	- Intrapersonal skills and why they matters? - How can engineers use intrapersonal skills to stay calm under pressure?	18.5 min	Circuits and systems education and outreach
	3	Emotional Intelligence: A Key to Personal and Professional Success	- Emotional intelligence - Self-awareness, why it matters and how can engineers develop it? - Self-management, why it matters and how can engineers develop it? - Time management benefits and techniques - Positive self-talk benefits and techniques	40.5 min	Circuits and systems education and outreach
	4	Coping with Workplace	Workplace stress and how can engineers minimise it?	25 min	

(continued)

Table 6. Continued.

Micro-course	No.	Micro-lesson title	Main contents	Learning time	BOK
Soft Skills for Responsible Engineers		Stressors: Strategies for a Healthy Work Environment	• Coping strategies and techniques for the workplace • Toxic positivity		Circuits and systems education and outreach
	5	Building Resilience and Adaptability: Navigating Challenges in the Workplace	• Resilience and adaptability at engineering workplace • Types and model of resilience • Benefits and impact of workplace adaptability	20 min	Circuits and systems education and outreach
	6	Introduction to Interpersonal Skills: Building Effective Connections	• Interpersonal skills for workplace to enhance safety and reliability • Social awareness for engineers • Social management for engineers • Do's and Don'ts tips at the workplace	28 min	Circuits and systems education and outreach
	7	Mastering Effective Communication: Building Strong Connections	• Effective communication at engineering workplace • Common barriers for effective communication • Types of communication (verbal and non-verbal) • Active listening and empathy • Addressing communication breakdown at the workplace	27 min	Circuits and systems education and outreach
Soft Skills for Responsible Engineers	8	Navigating Decisions and Solving Problems with Ease	• Problem-solving and Decision-making skills at engineering workplace • Tips for problem-solving and decision-making	25 min	Circuits and systems education and outreach
	9	The Art of Team Collaboration	• Collaboration and teamwork at engineering workplace • Technology to assist collaboration • Teambuilding phases and strategies at work • Diversity to strengthen teams	25 min	Circuits and systems education and outreach
	10	Unleash Your Leadership Brilliance: Navigating the Path to Effective Leadership	• Leadership at engineering workplace • Key leadership qualities • Leadership styles • Ethical leadership • Effective leadership skills	24 min	Circuits and systems education and outreach
	11	Ensuring Engineering Safety with Soft skills	• Soft skills case study scenarios • Expert forum discussion	41.5 min	Circuits and systems education and outreach

Our findings 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 IR4.0 demands.

4.3. Lessons learnt and opportunities for improvement

Incorporating TinyML and soft skills training into the engineering curriculum requires strategic planning and collaboration between educators, industry stakeholders and students. One effective strategy is to embed TinyML projects within existing engineering courses, ensuring that students gain practical, hands-on experience with real-world data and ML tools.

Another strategy is to offer standalone workshops or elective courses on TinyML and soft skills as part of the micro-credential program. These courses could feature guest lectures from industry experts, capstone projects and peer collaboration activities to give students a holistic learning experience. Regular industry feedback and mentorship throughout the course further bridge the gap between academia and professional practice, ensuring that students are equipped with the necessary skills for the workforce.

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. By maintaining flexibility and fostering collaboration between academic institutions and industry partners, micro-credential programs can remain a valuable tool for engineers seeking to enhance their skills and remain competitive in IR4.0 environments.

5. Conclusion

An open online platform micro-credential framework, BESTARI 4.0 that aligns IR4.0 skill drivers with concise learning modules has been proposed. The module couples resource-constrained TinyML techniques with soft-skill practice in critical thinking, communication and team problem-solving. Clear objectives, video labs, annotated notes, quizzes and real-world safety case studies foster project-based learning on the IEEE CASS platform. By bridging technical and interpersonal competencies, BESTARI 4.0 equips engineers to deploy ML solutions that raise both productivity and operational safety, offering a scalable template for future IR4.0 workforce development.

Integrating micro-credentials into engineering programs helps close the skills gap created by IR4.0. As automation and AI spread, engineers must master both advanced technical tools and soft skills. Micro-credentials deliver concise, industry-aligned training that builds this dual capability. Recent case studies show that well-designed micro-credential modules can boost technical expertise while strengthening problem-solving, creativity and project-management skills, giving graduates a clear market advantage. However, to unlock their full value, institutions must resolve challenges around employer recognition, quality assurance and a common implementation framework. Collaboration among universities, industry and policy-makers is essential. Adaptable micro-credentials will be central to the future of engineering education.

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Data availability statement

All data supporting the findings of this study are available from the corresponding author upon reasonable request.

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