Effectiveness of an Engineering-Led IR4.0 Training Program in Malaysia: A Qualitative Study

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ABSTRACT

As Malaysia accelerates its transition toward Industry Revolution 4.0 (IR4.0), the effectiveness of engineering-led training programs—especially among small and medium enterprises (SMEs)—remains underexplored. Existing evaluations often emphasize technical skills or student outcomes, neglecting organizational learning, cross-functional collaboration, and systemic readiness. This study addresses these gaps through a qualitative single-case study of the *Engineering Competence for IR4.0* training program by the Selangor Human Resource Development Centre (SHRDC), supported by a systematic literature review. Guided by the Technology-Organization-Environment (TOE) framework, Organizational Learning Theory (OLT), and Sociotechnical Systems (STS) perspective, thematic analysis of interviews with 12 engineering graduates highlights key challenges: departmental silos, limited integration, and inadequate post-training support. While participants gained foundational digital competencies, broader organizational transformation was constrained. In response, the study proposes the Integrated IR4.0 Training-to-Transformation (IITT) Framework—a novel model that aligns training content, learning mechanisms, and organizational enablers to support sustainable digital change. The research offers a localized, theory-informed understanding of why IR4.0 training often fails to scale beyond individual learning. It provides actionable insights for policymakers and training providers to design interdisciplinary, application-driven models. Ultimately, this study bridges individual skill acquisition with organizational alignment, contributing to digital capability development in emerging economies and laying the groundwork for future validation of the IITT framework.

Keywords—Industry 4.0 (IR4.0); Small and Medium Enterprises (SMEs); Engineering training; Digital transformation; Organizational learning; Malaysia.

INTRODUCTION

The Fourth Industrial Revolution (IR4.0) is transforming industries globally through the integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), cloud computing (CC), and big data analytics (BDA) [1,2]. To remain competitive, organizations—particularly small and medium enterprises (SMEs)—are increasingly under pressure to adopt these technologies and adapt their business operations. In response, many countries have launched national initiatives to accelerate digital adoption, such as Germany's Industrie 4.0, the United Kingdom's Industrial Strategy, and China's Made in China 2025.

In Southeast Asia, national strategies like Thailand 4.0 [3], Brunei Vision 2035 [4], Making Indonesia 4.0 [5], and Singapore's Industry Transformation Maps (ITMs) [6] reflect an ambition to transition toward high-income, innovation-driven economies. Malaysia has followed suit through Industry4WRD and the National 4IR Policy, which emphasize upskilling and structured training to drive digital integration [7]. Despite these top-down efforts, implementation at the organizational level—especially among SMEs—frequently encounters structural, cultural, and resource-related barriers [8-10].

A major component of Malaysia's IR4.0 push involves engineering-led training programs developed by government agencies and technical institutions. For instance, the Human Resource Development Corporation (HRD Corp) provides training in automation, cybersecurity, IoT, CC, BDA, and simulation technologies. Similarly, 360 Digi TMG, supported by Malaysia Digital Economy Corporation (MDEC), delivers IR4.0

modules that often assume participants possess prior technical knowledge. While technically focused training supports individual skill acquisition, it is increasingly recognized that digital transformation is a sociotechnical process requiring changes in organizational structure, culture, and leadership—not just technology adoption [11].

Previous studies have largely focused on technical upskilling or curriculum development [12–14]. However, few have evaluated whether such programs result in actual digital transformation at the organizational level, particularly within the SME sector in Malaysia. The STS perspective suggests that technology alone cannot drive meaningful change unless aligned with social and organizational dynamics [15]. Imbalances between technical systems and social subsystems often cause failure in transformation initiatives, particularly when innovation efforts lack alignment with broader societal structures and institutional dynamics [16].

One critical barrier is the persistence of organizational silos, which can manifest structurally (across departments) or culturally (as silo mentality). Structural silos refer to the fragmentation between functional units such as engineering, human resource (HR), and operations, leading to inconsistent goals and poor coordination [17, 18]. Silo mentality is a behavioural phenomenon marked by hoarding information, prioritizing departmental interests, and resisting interdepartmental collaboration [19]. Both types of silos impede digital transformation, but cultural silos particularly limit knowledge sharing and change acceptance. This study focuses on both structural and cultural silos, which inhibit open communication and collaboration across departments. Overcoming this barrier is critical to enhancing operational efficiency and productivity [17].

Initial field observations suggest that many IR4.0 training programs in Malaysia are developed and delivered in isolation, often without coordination with HR or operations departments. These programs risk becoming "siloed interventions" that improve individual competencies but lack the systemic integration necessary for transformation. Despite national support for structured training, SMEs struggle to translate individual learning into organization-wide innovation. This is evidenced by the fact that only 18% of Malaysian manufacturers have fully implemented IR4.0 technologies, while 46% remain in the early stages of adoption, and 13% have no adoption plans [20].

This raises the following research question: To what extent do engineering-led, technically focused training programs support or hinder digital transformation in Malaysian SMEs? Although prior research highlights the development of IR4.0 competencies [12-14], few studies investigate the organizational readiness, learning transfer, or cultural alignment needed to scale impact.

To address this gap, this study conducts a qualitative single-case study of an engineering-led IR4.0 training program in Malaysia. Through interviews with engineering graduates and guided by STS, OLT, and TOE frameworks, it examines how training interacts with silo mentality and organizational structure. The three theoretical lenses guide this analysis:

1. STS Theory explores how the interaction between technical systems and social structures determines transformation success [15]. When training is treated as a standalone technical intervention, it often fails to embed in broader workflows or team practices

2. OLT differentiates between *single-loop* learning (solving immediate problems) and *double-loop* learning (challenging assumptions and fostering adaptive change) [21]. Current IR4.0 training often reinforces single-loop learning, lacking mechanisms to support reflective, system-wide improvement

3. The TOE Framework contextualizes transformation as shaped not only by internal capabilities but also by external factors such as market conditions and government policies [22]. This lens helps explain why technical training alone is insufficient if not supported by strategic alignment and environmental readiness.

The study's main conclusion is that without organizational alignment, IR4.0 training risks remaining isolated and ineffective at driving transformation. It proposes a novel analytical model—the IITT Framework—that

emphasizes the alignment of training content, learning mechanisms, and organizational enablers. This model offers a practical roadmap for policymakers and training providers to design holistic, interdisciplinary training programs.

The findings are relevant not only to scholars of digital transformation and workforce development, but also to practitioners and policymakers seeking to implement effective IR4.0 strategies in emerging economies.

MATERIALS AND METHODS

A. Research Design

This study employed a qualitative single-case study design, supported by a systematic literature review (SLR). The dual-method approach served two objectives: (i) to explore participants' understanding and engagement with engineering-led IR4.0 training programs, and (ii) to assess the scarcity of Malaysian empirical studies evaluating such training at the organizational level.

The single-case study approach was selected for its ability to capture context-specific dynamics and deep insights, particularly relevant to digital transformation efforts within SMEs [23,24]. The selected case was the *Engineering Competence for Industry 4.0* program by the SHRDC—a not-for-profit ISO-certified institution active in SME talent development since 1992 in Malaysia.

The program provides practical, competency-based training focused on the enabling technologies of IR4.0. It emphasizes the development of technical skills and expertise necessary for the effective integration of IR4.0 technologies within manufacturing processes, aiming to enhance productivity, improve operational efficiency, and support sustainable digital transformation.

The training program comprised nine modules, completed in two months:

1. Basic Introduction to IR4.0
2. Electric Motor Control
3. Sensors and Transducers
4. Data Generation
5. IoT Gateway
6. Lean Manufacturing
7. Manufacturing Process Optimization
8. Overall Equipment Effectiveness (OEE)
9. Essential Programmable Logic Controller (PLC)

B. Systematic Literature Review (SLR)

An SLR was conducted to identify empirical studies evaluating IR4.0-related training within the Malaysian SME context. The review focused on studies analysing training design, delivery, and organizational outcomes.

Search Strategy and Eligibility Criteria

Searches were carried out in five academic databases: Scopus, Web of Science (WoS), ScienceDirect, Emerald Insight, and SpringerLink, using combinations of the following keywords:

- "IR4.0 training Malaysia"
- "Industry 4.0 upskilling"
- "technical and vocational education Malaysia"
- "TVET IR4.0"
- "digital competency SMEs Malaysia".

Inclusion and exclusion criteria are summarized in Table 1.

TABLE I. Inclusion and Exclusion Criteria.

Inclusion Criteria	Exclusion Criteria
Empirical studies (2021-2025)	Non-Malaysian contexts
Malaysia-based training programs	Book chapters or policy commentaries
Focus on digital skills, IR4.0, or transformation	Articles without measurable training outcomes
Target: SME workers, working adults, or technical graduates	Studies focused solely on student curriculum design

Review Findings

A total of 73 records were retrieved (Scopus = 15, WoS = 41, ScienceDirect = 10, Emerald = 6, SpringerLink = 1). Of these, 32 studies met the inclusion criteria and focused on:

- TVET and higher education training [12, 25–50]
- Lecturer readiness or digital teaching delivery [13, 51–53]
- Psychological capital intervention [14].

None evaluated organizational-level impacts or cross-functional integration within SMEs. This confirmed the research gap addressed in the current study.

Case Study Data Collection

Participants and Sampling

Twelve participants were selected using purposive sampling from SHRDC's IR4.0 program. Inclusion criteria were:

- Completion of the program
- Bachelor's degree in engineering (mechanical/electronics)
- Fulfilment of program eligibility (English proficiency, age 21–30, CGPA $\geq$ 3.0)
- Receipt of dual certification from Swiss Smart Factory and Malaysian-Swiss Smart Factory 4.0.

The sample size met the data saturation threshold for homogeneous qualitative samples [54].

Interview Protocol

Data were collected through semi-structured interviews with five open-ended questions exploring:

- Training effectiveness

- Cross-functional involvement
- Post-training application
- Organizational support and culture
- Suggestions for improvement.

Interview questions were theoretically informed by the STS theory, OLT, and TOE framework. To ensure clarity and alignment with the study's objectives, two pilot interviews were conducted with external engineering graduates.

Data Analysis

Thematic analysis followed the six-phase approach by Braun and Clarke [55]. An inductive coding strategy allowed themes to emerge directly from participant narratives. Codes were later mapped onto the theoretical frameworks for analytical depth. Table 2 provides illustrative quotes and their associated themes and lenses.

TABLE 2. Sample Quotes and Theoretical Mapping

Quote	Theme	Framework
"The training should involve business and IT departments too."	Cross-functional integration	TOE
"Engineers should explain tasks in simple terms."	Communication gaps	STS
"We need real-life case studies."	Experiential learning	OLT
"Training only focuses on machines."	Narrow scope	STS

Credibility was enhanced via peer debriefing and reflexive journaling to limit bias and strengthen analytical rigor [56].

RESULTS

This section presents the findings from the thematic analysis of the 12 participants involved in the SHRDC IR4.0 training program. Responses to five open-ended questions (Appendix A) were coded into seven initial themes, which were further refined into five final themes, as illustrated in Fig. 1.

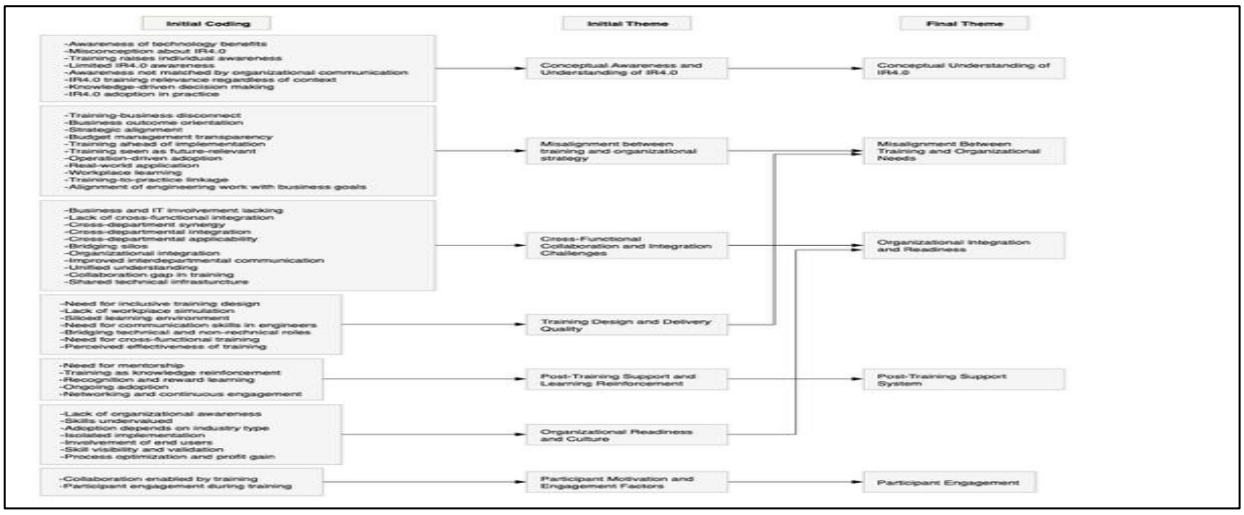

Fig. 1 Thematic Mapping from Initial Codes to Final Themes in the SHRDC IR4.0 Training Program.

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These themes reflect participants' experiences and perceptions related to IR4.0 training. The final themes include: (1) Conceptual Understanding of IR4.0, (2) Misalignment Between Training and Organizational Needs, (3) Organizational Integration and Readiness, (4) Post-Training Support, and (5) Participant Engagement. The themes is defined in the following sections.

Conceptual Understanding of IR4.0

This theme captures participants' foundational knowledge and awareness of IR4.0 concepts. Participants acknowledged that the training served as their first exposure to IR4.0, emphasizing its role in introducing key terms, digital technologies, and the broader implications of digital transformation.

Several respondents reported that the training significantly enhanced their understanding of how emerging technologies could be utilized in real-world business operations. For instance, Participant #5 explained, *"The training gave me a clearer picture of how technologies like automation, data analytics, and IoT can drive efficiency and decision-making in business operations."* Likewise, Participant #7 shared, *"I learned a lot about sensor applications, and now I deal with many sensors."* Participant #10 stated, *"The training especially helps in monitoring integrity parameters… so troubleshooting and bad actor identification are easier."*

However, the gap between theoretical knowledge and practical application remained a concern. Participant #11 stated, *"The training helped me understand algorithms and data collection, but I still need practical knowledge."* Others emphasized the benefits of the training even in non-technical roles, as Participant #5 noted, *"I gained awareness of technologies and their potential applications, which helped me understand future trends, though I don't work in a technical role."*

These reflections suggest that while the training effectively introduced IR4.0 principles, there is a need for more contextualized and applied learning to deepen understanding.

Misalignment Between Training and Organizational Needs

Participants expressed concerns about the mismatch between the training content and their company's actual operational goals or digital maturity. While the training covered various IR4.0 tools and theories, some participants felt the topics were either too general or not applicable to their immediate work environment. Participant #7 remarked, *"The training was useful, but my company hasn't implemented IR4.0 yet,"* indicating a misalignment between individual learning and organizational readiness.

In other cases, participants struggled to see tangible post-training benefits. Participant #8 observed, *"I understood the training, but it didn't help because I didn't get a related job afterward,"* and further suggested, *"Please be more effective with training—give more exposure to companies already applying IR4.0."* Others echoed the need for practical context, with Participant #5 recommending the inclusion of *"real-life case studies where business and IT teams successfully implemented IR4.0 solutions."* In addition, Participant #12 noted, *"More modules and more job offers are needed—my workplace doesn't support the application."*

Collectively, these responses indicate that a one-size-fits-all training approach may fall short without alignment to organizational contexts and career pathways.

Organizational Integration and Readiness

This theme reflects participants' perspectives on how well their organizations are prepared to implement IR4.0 technologies. It includes views on infrastructure, digital systems, leadership support, and internal collaboration. Participants noted that their companies lacked the readiness to adopt IR4.0 practices despite employee upskilling, highlighting a gap between individual learning and organizational transformation.

For instance, Participant #4 reported, *"We have no IT department here—management insists on formal meetings even when issues are already addressed digitally, which reduces productivity."* Similarly, Participant

#1 emphasized the need for broader collaboration, stating, *"We need cross-functional teams involved from the beginning of the project, not just during early phases."*

Others noted the challenges of working in sectors not directly aligned with IR4.0 implementation. Participant #3 reflected, *"My company is not manufacturing-based, so we don't use automation, but we help clients propose solutions."* Meanwhile, Participant #2 suggested, *"IR4.0 needs IT to increase sales—basic introduction to IT and business courses should be included."* Participant #10 added that *"financial transparency and budget planning are essential for IR4.0—business departments need to be involved."* These comments highlight that organizational readiness is critical for leveraging the full value of IR4.0 training.

Post-Training Support

Participants shared mixed experiences regarding follow-up support after the training. While some valued the resources and materials provided, others reported limited guidance, mentorship, or continuity. This theme underscores the importance of continuous learning opportunities, technical assistance, and knowledge transfer to sustain the momentum built during the training program.

Participant #1 stressed, *"post-training mentorship is recommended to assist early practice,"* while Participant #5 proposed *"pairing with professionals already in IR4.0 roles"* to facilitate knowledge transfer and real-world application. Others suggested institutionalizing support through incentives and recognition, as Participant #6 shared, *"Occasional workshops and Key Performance Indicator (KPI) incentives for IR4.0 projects would help sustain motivation."* The theme of workplace integration recurred in several responses, with Participants #7, #9, #11, and #12 all recommending it as a key strategy for maintaining momentum.

Additionally, Participant #5 proposed expanding post-training services to include *"job placement assistance or internships after training to help bridge the gap."* These findings point to the importance of extending learning beyond the training program to promote long-term adoption and impact.

E. Participant Engagement

This theme describes the level of motivation, participation, and interest shown by trainees throughout the program. Factors such as the relevance of training, delivery methods, practical activities, and peer interaction influenced engagement. Participants emphasized that collaborative, cross-functional participation was key to enhancing engagement and applicability. As Participant #5 observed, *"Discussions between IT, business, and engineering allow for better implementation."* Participant #4 echoed this view, noting that, *"Involving all departments would help everyone understand and apply IR4.0 more easily."*

Participants also called for a more unified approach to training delivery. For instance, Participant #1 recommended, *"Training should be engaging and connect participants from different departments with a common module."* Others linked engagement to perceived relevance and impact. Participant #2 commented, *"IR4.0 can accelerate business goals if departments work together—training should reflect that."*

However, not all participants viewed interdepartmental integration as necessary. Participant #12 shared, *"I don't think involving business and IT would help in my job because I'm not in a factory setting."* These mixed responses suggest that while inclusive, multidisciplinary training is broadly valued, it should also be adaptable to different professional roles and contexts.

DISCUSSION

The findings reveal a misalignment between individual learning outcomes and organizational readiness for IR4.0 transformation. While participants gained technical competencies indicative of single-loop learning [21], the absence of structural support limited the meaningful application of these skills in workplace settings. This echoes previous studies which suggest that without systemic alignment, training outcomes often fail to translate into organizational change.

For example, Bah et al. [57] show that employee involvement and organizational alignment are critical for successful change, otherwise transformation remains superficial. Similarly, Ramadania et al. [58] conclude that while digital training is necessary, it must be embedded within coherent organizational structures and leadership to drive measurable improvements. As Olmos-Vega et al. [56] underscore, qualitative evaluation of training must consider contextual factors—like institutional norms and power relations—that determine whether learning transfers beyond individuals to impact organizations.

From the STS perspective, siloed departmental structures and limited cross-functional collaboration inhibited the integration of training outcomes into everyday practice. This aligns with recent findings by Thomas [15], who investigated organizational transformation through knowledge management and highlighted the necessity of integrating motivation, technology, people interactions, and organizational systems to achieve meaningful change. When teams operate in silos without shared language or coordinated efforts, knowledge remains compartmentalized, undermining the impact of even well-designed training programs.

Informed by OLT, this study supports the view that training without enabling organizational conditions results in surface-level or single-loop learning. For example, platforms can help participants improve specific skills, but without organizational alignment, transformative (double-loop) learning—where underlying assumptions, strategies, and structures are questioned—remains rare.

A recent study by González-Varona et al. [59] found that manufacturing SMEs struggle to institutionalize digital competence when organizational culture, leadership, and strategy are misaligned with training objectives. Similarly, Gardner [60] observed in architectural design firms that training efforts frequently produce only incremental change when learning environments lack cross-boundary engagement and reflective practices.

These findings echo Argyris & Schön's [21] foundational model of double-loop learning and reinforce the necessity of structural readiness, leadership commitment, and cultural adaptability for fostering deeper organizational transformation.

The TOE framework helped contextualize the multi-layered barriers:

- Technological – absence of real-time simulation tools
- Organizational – fragmented goals, misaligned KPIs
- Environmental – limited regulatory incentives and market demand.

These findings align with research emphasizing the importance of ecosystem readiness in digital transformation. For example, Anatan and Nur [61] argue that successful adoption in micro-, small-, and medium enterprises depends on organizational alignment—including culture, leadership commitment, and infrastructural support—to move beyond superficial training outcomes. Similarly, Rozak et al. [62] found that readiness to change and agile leadership significantly strengthen SMEs' dynamic capabilities and digital ecosystems, highlighting how training alone is insufficient without organizational support.

Participants' suggestions—such as cross-functional training, real-world simulations, and improved communication modules—are supported by current literature. For instance, the Organizational Digital Transformation Readiness (ODTR) framework outlined by Maruping et al. [63] emphasizes embedding training into existing business processes, integrating diverse departmental roles, and reinforcing continuous learning across teams.

To address these gaps, this study introduces the Integrated IR4.0-Training-to-Transformation (IITT) Framework, a conceptual model that aligns training inputs, learning mechanisms, and organizational enablers. As illustrated in Fig. 2, the IITT framework provides a structured yet flexible roadmap to support holistic and scalable training initiatives, particularly for SMEs navigating IR4.0 adoption.

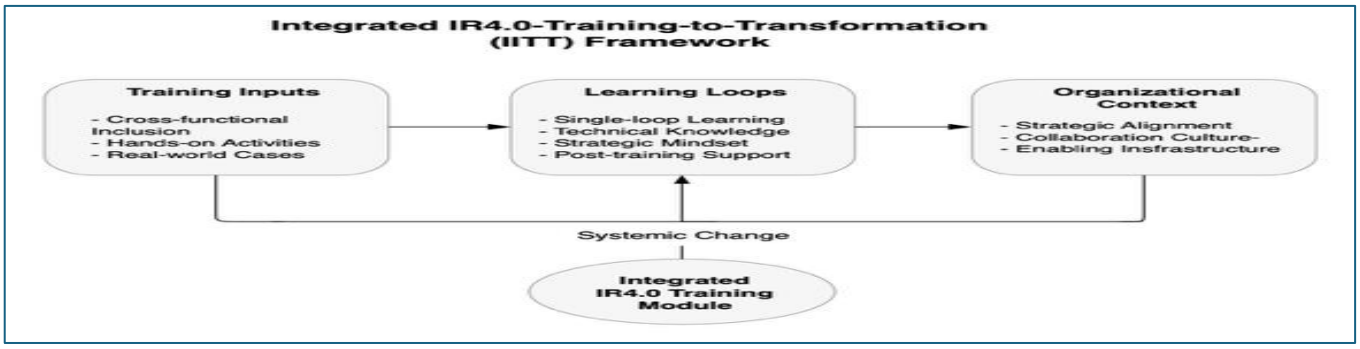

Fig. 2 Integrated IR4.0-Training-to-Transformation (IITT) Framework.

The IITT Framework offers a structured approach to understanding how IR4.0 training can lead to meaningful organizational transformation. The framework consists of three core components—Training Inputs, Learning Loops, and Organizational Context—which collectively contribute to systemic change when aligned effectively.

The first component, Training Inputs, refers to the foundational elements that shape the IR4.0 training experience. These include cross-functional inclusion (ensuring participants from diverse departments are involved), hands-on activities (to enhance engagement and practical understanding), and the use of real-world cases (to ensure relevance and applicability). These inputs are essential for delivering training that is immersive, collaborative, and reflective of actual workplace challenges.

The second component, Learning Loops, captures the internal processes triggered by training. This includes single-loop learning (where participants learn to correct actions within existing frameworks), the development of technical knowledge, and the cultivation of a strategic mindset that aligns individual learning with broader organizational goals. Additionally, post-training support is emphasized to sustain the momentum and application of new knowledge. These loops ensure that the training goes beyond surface-level understanding and fosters deep, ongoing learning.

For non-technical roles or departments, HR can adopt cloud-based platforms and AI-driven analytics to streamline recruitment and workforce planning, fostering single-loop learning and the application of technical knowledge. Similarly, the finance department can utilize automation tools for invoice processing and reporting, aligning with broader business efficiency goals. Post-training, these roles also contribute by supporting peer learning and reinforcing collaborative practices across departments.

The third component, Organizational Context, highlights the importance of the environment in which the training is implemented. For training to result in transformation, the organization must offer strategic alignment (between training objectives and business goals), promote a collaboration culture (where departments work together openly), and provide enabling infrastructure (systems, tools, and policies that support change). Without these contextual factors, even the most well-designed training may fail to deliver lasting impact.

For example, senior leadership can integrate IR4.0 training goals into the company's digital roadmap and performance indicators—such as, setting clear KPIs that link employee upskilling with automation targets or digital adoption milestones. To provide enabling infrastructure, companies can invest in cloud-based collaboration platforms, digital monitoring tools, and updated standard operating procedures (SOPs) that allow employees to apply their training seamlessly in daily tasks.

At the centre of the framework is the Integrated IR4.0 Training Module, which represents the core intervention informed by these three components. When training inputs, learning processes, and organizational conditions are cohesively integrated, they facilitate systemic change—a transformation that is embedded across the organization rather than isolated to individuals or departments.

These findings carry important implications for national and regional IR4.0 strategies. Technical training must be embedded within a broader transformation agenda that includes leadership development, cultural readiness, and system-wide strategic alignment. Otherwise, training risks becoming an isolated intervention with minimal strategic value—a conclusion supported by recent research on IR4.0 readiness failures.

For example, a large-scale study of 506 Malaysian SMEs found that leadership capability and strategic alignment were the strongest predictors of Industry 4.0 readiness, while workforce competency remained significantly lacking—emphasizing that technical or training interventions alone are insufficient without coordinated alignment across organizational dimensions [65].

CONCLUSION

This study examined the impact of an engineering-led IR4.0 training program—commonly siloed in technical scope—on participant experiences in Malaysia. Using thematic analysis informed by the STS perspective, OLT, and TOE framework, the study revealed critical insights into how such training influences the readiness of SMEs for digital transformation.

A. Implications for Practice

The findings highlight that siloed training programs, although valuable for technical upskilling, may fall short in achieving organizational-wide IR4.0 transformation. For training to catalyse real change, it must be holistic—integrating not only technological aspects but also organizational and human factors. Policymakers and industry leaders should consider embedding multi-stakeholder involvement and cross-functional learning to enhance training effectiveness. Additionally, the study's insights are valuable for institutions such as the Ministry of International Trade and Industry (MITI) and the Federation of Malaysian Manufacturers (FMM) in redesigning national IR4.0 training approaches to better serve the SME landscape.

B. Theoretical Contributions

This research contributes to the literature by applying the TOE, OLT, and STS lenses to understand the broader implications of IR4.0 training initiatives beyond technical adoption. It bridges a gap between technology-focused interventions and the socio-organizational realities of SMEs undergoing digital transformation. The integration of these theories offers a novel framework to assess IR4.0 readiness in contexts where traditional maturity models may be insufficient.

C. Limitations and Future Research

This study acknowledges several limitations that provide opportunities for future research. First, the participant sample primarily comprised engineering graduates, which may have constrained the diversity of perspectives—particularly from IT, business, or human resource personnel—who are equally critical to the cross-functional nature of IR4.0 implementation. This disciplinary imbalance limit the generalizability of the findings across broader organizational functions.

Second, while the proposed IITT Framework offers a structured conceptualization of training-to-transformation pathways, it remains untested in real-world settings. The framework is currently theoretical, and no pilot testing or empirical validation has been conducted to assess its applicability or practical effectiveness. Future studies should focus on piloting the framework within SME environments to evaluate its operational utility and refine its components based on real-time feedback. It would also be valuable to examine the long-term impact of such training programs on organizational performance and workplace culture. For instance, future research could assess how key functionalities of digital tools, such as Workshop Management Systems (WMS), are integrated within training outcomes [64].

Third, although the study is grounded in a Malaysian context, its findings would benefit from broader contextualization. Future work should explicitly relate local training challenges to global trends in IR4.0 adoption—particularly regarding scalability, workforce readiness, and policy frameworks within developing economies.

Additionally, the study relied solely on semi-structured interviews as the primary data source. While interviews provide rich qualitative insights, the lack of triangulation with supplementary data—such as organizational documents, training materials, or direct observations—limits the depth and robustness of the analysis. Future research is encouraged to adopt a mixed-methods approach to strengthen methodological credibility and validate emerging themes.

Finally, the study did not comprehensively explore internal power dynamics, organizational politics, or resistance to change—factors that often critically influence the success or failure of transformation initiatives. Subsequent investigations should delve deeper into these sociocultural and political dimensions to offer a more holistic understanding of the barriers to training-led transformation. Expanding the analysis to incorporate local cultural influences and linking these with global IR4.0 scalability issues would further enrich the discussion and enhance the applicability of the findings across diverse contexts.

Appendix A

This appendix provides the five open-ended questions asked to the 12 participants (mechanical and electronics engineering graduates) of the *Engineering Competence for Industry 4.0* training program. These questions aimed to explore participants' views on training design, implementation, and its applicability in the workplace:

1. Has your organization adopted or started to adopt IR4.0 technologies since the training? If yes, how did the training contribute?
2. Did the training help you understand how IR4.0 technologies connect to business strategy or IT systems? Please explain.
3. How can the training be improved to include or engage departments like business and IT?
4. Do you think involving business and IT departments in the training would have helped you apply IR4.0 more effectively in your job? Why or why not?
5. What support mechanisms (e.g., post-training mentorship, workplace integration) do you recommend for sustaining the momentum gained during training?

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