Developing and Evaluating the Process Control and Instrumentation Trainer: A Systematic Review of Curriculum Readiness and Technology Utilization in Philippine TVET

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ABSTRACT

The global industrial transition toward the Fourth Industrial Revolution (4IR) requires a substantial realignment of technical-vocational training methods. Within the Philippine Technical-Vocational Education and Training (TVET) sector, particularly in Electrical Technology, there remains a persistent "theory-practice gap" caused by a mismatch between modern industrial standards and actual workshop instruction. This research paper provides a systematic assessment of the instructional and curricular readiness of TVET programs for industrial automation and process control. By synthesizing the Technology Acceptance Model (TAM) with experiential learning principles, this paper evaluates preparation across four core dimensions—Technical functionality, Alignment with standards, Readiness of staff, and Integration of pedagogy—collectively referred to as the T-ARI framework. The study reviews research, national policy directives from the Technical Education and Skills Development Authority (TESDA), and institutional academic audits published from 2020 to 2026. The novelty of this study lies in its grounded focus on the intersection of equipment sustainability and instructor readiness in resource-constrained regional training blocks. The findings indicate that while national competency standards emphasize instrumentation and control, actual classroom implementation is often hindered by equipment underutilization, where trainers are left unused or poorly maintained. Furthermore, instructor anxiety regarding complex automated logic and a lack of localized instructional materials continue to constrain student learning. Ultimately, the integration of durable, TESDA-aligned training simulators represents a strategic progression toward reducing the skills mismatch and ensuring national qualification readiness in an increasingly automated workforce.

Keywords: Automation pedagogy, curriculum readiness, experiential learning, instrumentation trainer, process control, technology utilization, TVET readiness.

INTRODUCTION

The global industrial sector is experiencing a significant transition as conventional mechanical processes are increasingly integrated with automated control systems (Lee, 2024; TVET Online, 2022). Internationally, technical and vocational education and training (TVET) institutions are increasingly tasked with preparing a workforce capable of maintaining and troubleshooting these complex configurations (Kamaruzaman et al., 2024). These global shifts toward automation and the Fourth Industrial Revolution serve as the primary drivers for national training mandates, requiring students to possess both theoretical knowledge and practical technical mastery (TESDA, 2023).

In the Philippines, this industrial demand is reflected in the Technical Education and Skills Development Authority (TESDA) competency standards, which emphasize the need for industry-ready technicians in the fields of instrumentation and control (TESDA Training Courses, 2023). To meet these national standards, technical-vocational electrical technology programs must provide students with hands-on exposure to modern control logic. However, despite the existence of these policy frameworks, a consistent gap remains between the intended curriculum and the actual classroom experience (Orbeta & Corpus, 2024; PIDS, 2023).

While global trends push for high-level automation, the local reality in many Philippine TVET centers is characterized by persistent challenges such as skills mismatches and inadequate laboratory facilities (TESDA, 2022; JIP Publication, 2021). A recurring issue in provincial and regional training blocks is not only the scarcity of equipment but also the underutilization of existing process control and instrumentation trainers. In many instances, these instructional tools remain unused or poorly maintained, which limits students' exposure to real-world applications and weakens their readiness for industrial employment (ResearchGate, 2023; Orbeta & Corpus, 2024). This misalignment suggests that the mere presence of hardware is insufficient if the institutional capacity and instructional materials are not properly aligned with the equipment (Pascua & Lagunero Tagare, 2024).

The novelty of this study lies in its specific focus on the intersection of equipment utilization and curriculum readiness within the Philippine context. While broad literature exists on TVET pedagogy, there is a distinct lack of a systematic review that evaluates how localized, sustainable process control trainers can specifically address the issues of maintenance and instructor readiness in rural and resource-constrained campuses. By synthesizing recent research and institutional audits, this paper provides a grounded assessment of how a TESDA-aligned instrumentation trainer can be effectively integrated into existing workshops to bridge the gap between classroom theory and industrial practice (Lee, 2024; TESDA, 2023).

Ultimately, this systematic literature review aims to consolidate current findings to guide the development of accessible and durable training tools. By evaluating the institutional and human factors that influence technology adoption, this study seeks to offer a practical roadmap for TVET educators and administrators to improve the quality of hands-on learning and ensure that graduates meet the immediate demands of the local and international industrial sectors (World Bank, 2024; Mishra & Koehler, 2006).

CONCEPTUAL AND THEORETICAL FRAMEWORK

The integration of a Process Control and Instrumentation Trainer into the technical-vocational electrical technology curriculum represents more than the simple addition of hardware; it is a systemic effort to align classroom instruction with industrial realities (Jondra & Sugiarta, 2021). To understand why some institutions succeed in this integration while others struggle with equipment underutilization, it is necessary to examine the interaction between pedagogical requirements and institutional capacity (Fullan, 2007, 2020). This paper evaluates these factors using a synthesized framework that combines the principles of Experiential Learning with a focused assessment of curriculum readiness.

Concept of Curriculum Readiness

Curriculum readiness in the TVET sector is defined by the degree to which a training program is prepared to implement new technical content and maintain the necessary instructional tools (Azman et al., 2025). In the context of instrumentation and control, readiness is not a static state but a dynamic condition characterized by four interconnected dimensions, collectively referred to here as the T-ARI Model:

- Technical Functionality and Sustainability: This dimension refers to the physical reliability and maintainability of the trainer. A significant barrier in local TVET centers is the presence of equipment that is "left unused" due to a lack of spare parts or technical knowledge for upkeep (Orbeta & Corpus, 2024). Readiness requires that the trainer be durable and accessible for long-term use.
- Alignment with Competency Standards: This involves the direct mapping of the trainer’s functions to the National Certificate (NC) requirements set by TESDA. To be effective, the instructional tool must allow students to perform specific tasks that mirror industry-grade competencies in automation and process control (TESDA, 2023).
- Readiness (Institutional and Human): This parameter focuses on the proficiency of instructors and the availability of school facilities. Institutional readiness suffers when trainers are provided without concurrent training for the teachers, leading to the "underutilization" of modern laboratory equipment (PIDS, 2023; TESDA, 2022).
- Integration of Experiential Learning: This dimension evaluates how the trainer is used to bridge the gap between classroom lectures and workshop practice. It emphasizes hands-on, student-centered activities that reduce "cognitive friction" and allow learners to visualize complex control logic (Schmidt, 2024; Lee, 2024).

Operational Matrix of the T-ARI Framework

To ensure the structural coherence of the review, the core dimensions of the T-ARI framework are mapped against specific operational indicators within the TVET workshop and the corresponding technical competencies required by modern industry. This matrix provides a clear metric for evaluating whether a training institution is merely possessing hardware or is truly "ready" for technology integration.

Table 1: Mapping T-ARI Dimensions to Operational Indicators and Industry Competencies

T-ARI Dimension	Operational Indicators (TVET Context)	Corresponding Industry Technical Competencies
Technical Functionality & Sustainability	Equipment uptime/downtime rates; Availability of localized spare parts; Maintenance log consistency.	System Reliability & Upkeep: Ability to perform preventative maintenance and hardware troubleshooting on live industrial lines.
Alignment with Competency Standards	Adherence to TESDA NC II/III Training Regulations; Mapping of trainer tasks to National Assessment criteria.	Quality & Compliance: Mastery of standardized operational procedures and adherence to national safety and electrical protocols.
Readiness (Institutional & Human)	Percentage of instructors with NTTC/TM1 certification; Safety-insulated laboratory ratings; Instructor confidence in automation logic.	Advanced Diagnostics: Proficiency in industrial automation, PLC logic, and the diagnosis of complex integrated circuits.
Integration of Experiential Learning	Student-to-equipment ratio; Utilization rate of localized laboratory manuals; Frequency of hands-on simulation vs. theory.	Process Execution: Capability to visualize "invisible" control logic and execute real-world process adjustments in a high-pressure environment.

Experiential Learning and Technology Adoption

The behavioral aspects of adopting new training tools are further explained by the Technology Acceptance Model (TAM). Originally formulated by Davis (1989), TAM suggests that a teacher’s willingness to use a process control trainer depends on its *Perceived Usefulness* (PU) and *Perceived Ease of Use* (PEOU) (Al-Emran & Granić, 2024). In many Philippine TVET institutions, if a trainer is perceived as too complex to operate or too difficult to maintain, it is likely to be abandoned in favor of traditional, manual-based instruction (ResearchGate, 2023).

By synthesizing these variables, the T-ARI Model acknowledges that successful technical training is a collaborative endeavor. It suggests that for a Process Control and Instrumentation Trainer to be effectively utilized, there must be a balance between the technical quality of the tool, its alignment with national standards, and the readiness of the staff to integrate it into daily lessons. This framing demonstrates that "readiness" is not merely about purchasing equipment, but about ensuring that the equipment, the curriculum, and the instructor are in constant structural alignment (Hargreaves & Shirley, 2019).

METHODOLOGY

In order to consolidate and analyze current literature, empirical studies, and policy frameworks concerning technical-vocational instrumentation education, this paper implements a comprehensive systematic literature review methodology (Pecson & Sarmiento, 2025). In contrast to broad narrative evaluations, this structured approach employs an explicit search and filtration protocol to gather recent empirical findings regarding the use of process control trainers in TVET settings (Pecson & Sarmiento, 2025).

Information Sources and Search Strategy

A comprehensive electronic search was executed across prominent index databases, including Google Scholar, Scopus, ResearchGate, and the Philippine Journals Online (PhilJOL) archive. To secure highly relevant, highcurrency literature reflecting modern industrial shifts and local institutional realities, the search protocol was restricted to articles, policy documents, and academic audits published between 2020 and 2026.

The search strings were constructed using specialized boolean operators and keywords tailored to the research topic: ("process control" OR "instrumentation trainer") AND ("TVET" OR "electrical technology"), ("skills mismatch" OR "equipment utilization") AND ("Philippines" OR "TESDA"), and ("hands-on learning" OR "curriculum readiness") AND ("automation education").

Literature Selection: Inclusion and Exclusion Criteria

To filter the retrieved documents with precision and eliminate selection bias, an explicit matrix of eligibility boundaries was established. To be included in the final qualitative synthesis pool, documents had to meet four specific parameter thresholds:

1. Temporal and Language Parameters: Studies must be published in the English language between 2020 and 2026 to capture post-pandemic instructional shifts and updated national qualification standards.
2. Contextual Parameter: Materials must directly focus on technical-vocational frameworks, instrumentation and control tracks, or industrial automation training pipelines.
3. Core Operational Parameter: Research must address the design, maintenance, utilization, or institutional integration of training hardware (e.g., simulators, localized kits, or laboratory trainers).
4. Target Demographic Parameter: The empirical sample must focus on TVET students, vocational instructors, or institutional stakeholders within regional or rural training blocks, rather than purely theoretical or high-capital industrial manufacturing settings.

Conversely, papers focusing exclusively on general computer literacy or highly automated, large-scale industrial systems without application to the TVET workshop context were excluded to maintain focus on the grounded challenges of local institutions.

Thematic Synthesis and Analysis

A thematic synthesis methodology was employed, informed directly by the integrated parameters of the T-ARI Model (Technical, Alignment, Readiness, and Integration). The review involved the systematic identification and classification of literature addressing topics such as tool durability, teacher preparedness, institutional facilities, and national policy support from TESDA. Each document was examined to determine whether top-down national standards were consistent with the actual physical manner in which instrumentation and process control were being taught at the school workshop level. Thematic coding facilitated the identification of instructional weaknesses and regional opportunities for improving the utilization of existing training equipment (Pecson & Sarmiento, 2025).

RESULTS AND DISCUSSION

Table 2 summarizes the findings from empirical studies, policy reports, and institutional audits (2020–2026) regarding the integration and utilization of process control and instrumentation trainers. These findings are categorized according to the dimensions of the T-ARI framework to provide a grounded assessment of current TVET readiness.

Table 2: Summary Review of Key Findings

Theme	Key Findings	Sources
Technical Functionality & Sustainability	Many institutions possess trainers that are "left unused" or poorly maintained. There is a lack of localized support for technical upkeep, leading to the eventual abandonment of complex instructional hardware.	Orbeta & Corpus (2024); ResearchGate (2023); Dela Cruz (2024)
Alignment with Industry Standards	National training mandates (TESDA) emphasize 4IR and automation, yet a significant skills mismatch persists. Graduates often lack the specific competencies required for modern industrial instrumentation.	TESDA (2023); Lee (2024); PIDS (2023); JIP Publication (2021)

Institutional & Human Readiness	Skills gaps are observed among instructors who struggle to operate or teach with modern control systems. Regional training blocks frequently face equipment scarcity and inadequate laboratory facilities.	TESDA (2022); Ahmad & Wrahatnolo (2024); Al-Emran & Granić (2024)
Integration of Experiential Learning	Hands-on trainers effectively bridge the "theory-practice gap," but their success depends on the availability of structured laboratory manuals and user-friendly interfaces to reduce student anxiety.	Lee (2024); Schmidt (2024); Pascua & Lagunero Tagare (2024)

Technical Functionality and Sustainability

The review indicates that the mere acquisition of process control trainers does not guarantee instructional success. A recurring localized problem in Philippine TVET centers is the "underutilization" of existing equipment. Trainers are often delivered to schools but eventually become idle due to minor technical malfunctions or a lack of specialized maintenance protocols (Orbeta & Corpus, 2024). Studies suggest that for technical education to be sustainable, training tools must be designed for durability and accessibility, allowing for long-term use in resource-constrained environments (ResearchGate, 2023). Without a plan for technical upkeep, even modern trainers fail to serve their purpose, leading to what is described as "instructional poverty" despite the presence of hardware (Pascua & Lagunero Tagare, 2024).

Alignment with Industry and Competency Standards

There is a documented misalignment between top-down policy intentions and the actual competencies of graduates. While TESDA (2023) has updated its standards to include 4IR technologies and complex instrumentation, local graduates often lack the hands-on proficiency required by industry partners (PIDS, 2023). This "skills mismatch" is largely attributed to the fact that many training programs still rely on theoretical or two-dimensional schematics rather than interactive, physical process control systems (JIP Publication, 2021). The findings suggest that bridging this gap requires trainers that are explicitly mapped to national certification (NC) requirements, ensuring that every workshop activity directly translates to a marketable industrial skill (TESDA Training Courses, 2023; Lee, 2024).

Institutional and Human Readiness

The effectiveness of a process control trainer is heavily dependent on the readiness of the instructor and the adequacy of the campus facilities. Many educators in the vocational sector were trained in traditional electrical fields and may lack formal certification or experience in modern automated systems (Andal et al., 2022). This instructor anxiety often results in trainers being left in storage to avoid damage or due to a lack of confidence in demonstrating their operation (Ahmad & Wrahatnolo, 2024). Furthermore, rural and provincial campuses continue to face "equipment scarcity," where a single trainer must serve a large cohort of students, significantly reducing the quality of individual hands-on practice (TESDA, 2022; Solidum, 2023).

Integration of Experiential Learning

Ultimately, the role of an instrumentation trainer is to facilitate experiential learning by making "invisible" control logic visible to the student (Lee, 2024). The literature suggests that students who use transparent, well-structured simulators show higher behavioral intentions to adopt technical innovations and lower levels of cognitive load (Al-Emran & Granić, 2024; Schmidt, 2024). However, for this integration to be successful, the trainer must be accompanied by localized instructional materials that guide the student through real-world troubleshooting scenarios. Without these practical guides, the hardware remains a static object rather than a dynamic teaching tool (Pascua & Lagunero Tagare, 2024).

RECOMMENDATIONS

To enhance the institutional utilization of process control and instrumentation trainers, it is recommended that TVET institutions establish localized maintenance protocols and sustainability plans to prevent equipment from remaining idle due to minor technical malfunctions or a lack of specialized upkeep. Furthermore, technical-vocational administrators must prioritize instructor upskilling through national-scale workshops focusing on industrial automation and control systems, thereby reducing teacher anxiety and fostering the technical confidence necessary to integrate trainers into daily workshop instruction. This development of human capacity should be paired with the creation of localized, user-friendly instructional manuals that simplify complex control logic for students, alongside regular curriculum audits to ensure that every workshop activity remains perfectly aligned with TESDA competency standards and the evolving demands of the industrial sector.

CONCLUSION

Ultimately, the integration of a Process Control and Instrumentation Trainer into the TVET system serves as a crucial strategic response to the technical demands of the Fourth Industrial Revolution, though its effectiveness is currently constrained by persistent gaps in institutional readiness. This review demonstrates that while national frameworks like TESDA provide the necessary policy momentum, actual workshop implementation continues to struggle with equipment underutilization, a lack of technical maintenance, and uneven instructor proficiency regarding automated systems. By applying the T-ARI Model—Technical functionality, Alignment with standards, Readiness of staff, and Integration of experiential learning—it becomes clear that bridging the theory-practice gap requires more than the mere provision of hardware; it necessitates a cohesive effort to maintain equipment functionality, enhance human capacity, and align instructional tools with real-world industrial needs. Addressing these localized challenges is essential for reducing the existing skills mismatch, ensuring that Philippine TVET graduates possess the hands-on mastery required to achieve national qualification readiness and succeed in an increasingly automated global workforce.

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