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Design and Development of an Air-Conditioning System Mock-Up Trainer

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ABSTRACT

This study focuses on the design and development of an Air-Conditioning System Operation Mock-up Trainer with accompanying instructional materials to address limited practical learning opportunities in vocational education, where existing instruction often overemphasizes theory due to scarce functional trainers and incomplete instructional resources. Grounded in the Analysis, Design, Development, and Evaluation framework, the study proceeded through three phases: needs assessment, prototype design and fabrication, and expert validation. In the needs assessment, an adapted questionnaire with good internal consistency (Cronbach's α=.873) was administered via purposive sampling to 32 TVET respondents (8 teachers, 24 students) in Misamis Occidental. Results confirmed strong agreement on the need for a dedicated trainer (M=3.41,SD=0.50) and the scarcity of instructional materials (M=2.94,SD=0.62), with all core components rated "Very Important" (M=3.72–3.81). Content validity of the needs-assessment tool was confirmed by four Subject Matter Experts (SMEs), yielding an Item-Level CVI of 1.00 and Scale-Level CVI of 1.00 (S-CVI/Ave and S-CVI/UA), reflecting complete agreement within the panel. The prototype was fabricated using real working components mounted on a mobile rack. Validation of the physical trainer by five SMEs yielded "Very Good" to "Excellent" ratings across technical accuracy (M=4.70,SD=0.45), usability and labeling (M=4.90,SD=0.32), and safety (M=4.53,SD=0.42). A dedicated evaluation of the accompanying instructional materials produced mean ratings ranging from 4.60 to 5.00 across content, clarity, and usefulness. The findings demonstrate that the trainer and materials are technically accurate, safe, usable, and suitable for instructional adoption in technical-vocational education.

Keywords: Air-Conditioning System, Mock-up Trainer, instructional design, technical vocational education, practical learning, needs assessment, expert validation.

INTRODUCTION

Education is a cornerstone of workforce development, particularly in industries that depend on skilled technicians to operate and maintain complex equipment. Yet instruction across technical-vocational institutions globally overemphasizes theory, leaving students with limited opportunities to translate conceptual knowledge into hands-on competencies (Oviawe, 2017). This persistent gap between educational content and industry requirements results in graduates inadequately prepared for the realities of the workplace (Cheruiyot, 2025; Nkwanyane, 2023; Rahayu et al., 2025; Tjahjono et al., 2025). Compounding this challenge, many vocational colleges rely on outdated equipment that no longer matches current industrial changes, forcing teachers to resort to theoretical delivery because resources for practical training remain scarce (Chola & Kiplagat, 2025; Nkwanyane, 2023).

This concern is reinforced by global policy frameworks. The 2030 Agenda for Sustainable Development positions Goal 4 on Quality Education—particularly Targets 4.3 and 4.4—as the central reference for technical-vocational training, calling for equal access to affordable, quality TVET and a substantial increase in youth and adults with relevant skills for employment, decent jobs, and entrepreneurship (Adriansen, 2016;

McGrath & Powell, 2016; Storonyanska et al., 2025). Goal 8 on Decent Work and Economic Growth links skills development to inclusive economic participation (Adriansen, 2016; Chola & Kiplagat, 2025; Storonyanska et al., 2025), while Goal 9 on Industry, Innovation, and Infrastructure requires the upgrading of technological capabilities in industrial sectors and the modernization of training facilities (Edbais & Hossain, 2025; Küfeoğlu, 2022; Wahab et al., 2025). Collectively, these agendas frame the design of functional training tools as aligned with sustainable development goals (Chola & Kiplagat, 2025; Jayaprakash, 2024; Storonyanska et al., 2025).

Among the technical disciplines affected, refrigeration and air-conditioning (RAC) technology is particularly critical given the widespread use of cooling systems in residential, commercial, and industrial settings. Air-conditioning systems comprise interrelated components—the evaporator, condenser, compressor, and thermal expansion valve—that must work together precisely to deliver proper cooling performance (Baldos & Sabang, 2025; Tagle, 2023). A thorough understanding of each component, how they interact, and how the system responds to operational changes is essential for students pursuing careers in HVAC installation, servicing, or troubleshooting.

Despite growing policy attention, however, available training resources in many local institutions remain inadequate. Functional mock-up trainers that simulate real air-conditioning systems using actual working components are rarely available, and supporting instructional materials are often incomplete or absent. This shortage forces TVET teachers to depend on theoretical delivery, since the tools and equipment needed for hands-on RAC training in workshops are lacking (Baldos & Sabang, 2025; Nkwanyane, 2023). Without adequate hands-on exposure, learners struggle to develop diagnostic reasoning and troubleshooting skills, perpetuating the gap between graduate competencies and workplace demands (Cheruiyot, 2025; Chola & Kiplagat, 2025; Tjahjono et al., 2025).

To address this concern systematically, the study employs selected phases of the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) instructional design framework—a systematic learner-centered model that proceeds from needs analysis through prototype fabrication to evaluation (Peterson, 2003; Shakeel et al., 2022). ADDIE has been successfully applied in technical-vocational contexts for developing valid and practical instructional media, ensuring that the eventual trainer is both technically sound and pedagogically aligned with learner needs (Shakeel et al., 2022; Stapa & Mohammad, 2019).

This study aims to design and develop an Air-Conditioning System Operation Mock-up Trainer with corresponding instructional materials for potential adoption in technical-vocational education. Specifically, it assesses local training needs, designs and fabricates the trainer using real working components, and validates both the physical prototype and accompanying instructional materials through expert evaluation. Analogous R&D studies on AC and refrigeration trainers report strong ratings of validity and practicality (Afriwandi et al., 2025; Baldos & Sabang, 2025; Tagle, 2023). By producing a functional prototype grounded in an established developmental framework, the study supports ongoing efforts to upgrade training infrastructure in TVET programs.

Statement of the Problem

This study aimed to develop and validate an Air-Conditioning System Mock-up Trainer with accompanying instructional materials. Specifically, this study sought to answer the following research questions:

1. What are the needs and current challenges encountered in the teaching and learning of Air-Conditioning System operation in terms of:

    1.1 Necessity for a new Air-Conditioning System trainer?

    1.2 Current instructional challenges?

2. What components and content are considered important for inclusion in an Air-Conditioning System Trainer?

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3. What is the level of validity of the Air-Conditioning System Trainer in terms of:

    3.1 Technical accuracy?
    3.2 Usability and labeling?
    3.3 Safety and durability?

4.What is the level of validity of the accompanying instructional materials in terms of:

    4.1 Content?
    4.2 Clarity?
    4.3 Usefulness?

METHODOLOGY

Research Design

The study employed a descriptive-developmental research design, consistent with comparable R&D efforts on air-conditioning and refrigeration training tools. Development proceeded through three sequential phases: needs assessment, prototype design and fabrication, and expert validation.

The developmental process was guided by the initial phases of the ADDIE instructional model (Analysis, Design, Development, and Evaluation). In this study, the Analysis phase comprised the needs assessment among local instructors and students; the Design and Development phases encompassed component selection, electrical/refrigeration schematic layout, and physical rack fabrication; and the Evaluation phase involved expert validation of the physical prototype and instructional materials by Subject Matter Experts. Full student classroom implementation and longitudinal learning outcome measurements were beyond the scope of this development-and-validation study and are reserved for future quasi-experimental testing.

Analysis Needs Assessment (N=32 TVET)	→	**Design and Development** Component Selection, Rack Fabrication	→	**Evaluation** SME Prototype and Instructional Rubrics

Participants and Sampling

Two distinct respondent groups were purposively selected for the study: Needs-Assessment Respondents (N=32), comprising 8 TVET instructors with an average of 8.5 years of teaching experience and 24 Industrial Arts students enrolled in refrigeration and air-conditioning (RAC) modules from selected institutions in Misamis Occidental—all chosen to ensure direct classroom or workshop exposure to RAC instruction—and Subject Matter Experts (SMEs), who were divided into two specialized panels to meet developmental validation requirements. Within the SME group, a Survey-Validation Panel (n=4) consisting of senior TVET educators evaluated the content validity of the Needs Assessment Questionnaire using a 4-point relevance scale, while a Prototype-Validation Panel (n=5) composed of licensed mechanical/electrical engineers and master TVET instructors—each bringing over 10 years of industrial and pedagogical HVAC experience—evaluated the physical trainer and accompanying instructional materials.

Research Instruments

Three research instruments were utilized in the study: an adapted 19-item Likert-scale Needs Assessment Questionnaire capturing the perceived necessity for a trainer, instructional challenges, and essential components (demonstrating good internal consistency with a Cronbach's α=.873); a Needs-Assessment Survey Validation Rubric administered to four SMEs using a 4-point scale (1=not relevant to 4=highly relevant) to compute Item-Level and Scale-Level Content Validity Indices (I-CVI, S-CVI/Ave, S-CVI/UA); and an adapted Expert Validation Rubric employing a 5-point rating scale (5=Excellent to 1=Poor) to evaluate both the physical prototype across technical accuracy, usability/labeling, and safety/durability, as well as the instructional materials in terms of content, clarity, and usefulness.

Data Gathering Procedure

Data collection followed a structured, five-step procedure beginning with securing institutional permission and informed consent to guarantee voluntary participation, anonymity, and confidentiality (Step 1). Next, the needs-assessment questionnaire was distributed to the 32 instructor and student respondents (Step 2), while four SMEs reviewed the content relevance of this assessment tool (Step 3). Guided by these user requirements, core functional components—including a compressor, condenser, evaporator, thermal expansion valve, thermostat, filter drier, circuit breaker, and pressure gauges—were procured and mounted on a mobile timber frame with caster wheels, with electrical wiring designed following safety principles from the Philippine Electrical Code (PEC) and low-voltage standards, and tubing layouts reviewed against educational safety principles inspired by ASHRAE Standard 15 (Step 4). Finally, five SMEs independently inspected and evaluated both the fabricated trainer and its accompanying manual (Step 5).

Data Analysis

Quantitative data were analyzed using descriptive statistics, specifically utilizing means and standard deviations (SD) to summarize item-level and dimension-level responses. To determine content validity, Content Validity Indices (CVI) were calculated, where the Item-Level Content Validity Index (I-CVI) represented the proportion of experts rating an item as relevant (score ≥3), the Scale-Level Content Validity Index Universal Agreement (S-CVI/UA) indicated the proportion of items achieving 100% expert agreement, and the Scale-Level Content Validity Index Average (S-CVI/Ave) reflected the overall mean I-CVI across all items. Obtained mean scores for the Needs Assessment and Component Importance were interpreted using a four-point continuum: 3.26–4.00 (Strongly Agree / Very Important), 2.51–3.25 (Agree / Important), 1.76–2.50 (Disagree / Slightly Important), and 1.00–1.75 (Strongly Disagree / Not Important). Meanwhile, mean scores for the Expert Validation Rubric were interpreted using a five-point evaluation scale: 4.50–5.00 (Excellent), 3.50–4.49 (Very Good), 2.50–3.49 (Good), 1.50–2.49 (Fair), and 1.00–1.49 (Poor).

RESULTS

Reliability and Content Validity of the Needs Assessment Tool

The 19-item Needs Assessment Questionnaire demonstrated good internal consistency (α=.873). Content validity evaluation by four SMEs yielded perfect agreement across all items (I-CVI=1.00, S-CVI/Ave=1.00, S-CVI/UA=1.00). While perfect agreement among a small panel (n=4) indicates excellent face and content relevance for the local target setting, it is interpreted as strong preliminary instrument adequacy rather than absolute standardization across broader populations.

Needs Assessment and Subgroup Disaggregation

Table 1 presents the overall and disaggregated needs-assessment findings for teachers (n=8) and students (n=24).

Table 1 Perceived Necessity and Current Instructional Challenges in AC Operation Instruction

Item Statement	Teacher Mean (n=8)	Teacher SD	Student Mean (n=24)	Student SD	Overall Mean (N=32)	Overall SD	Interpretation
1. Current teaching methods adequately cover only the theoretical aspects of AC systems.	3.00	0.53	2.71	0.55	2.78	0.55	Agree
2. Students lack sufficient access to an AC trainer with real components and functions.	3.13	0.35	2.83	0.48	2.91	0.47	Agree

3. A dedicated AC Mock-up Trainer would significantly improve practical learning opportunities.	3.63	0.52	3.33	0.48	3.41	0.50	Strongly Agree
4. Current training equipment does not include all necessary operational components.	3.00	0.53	2.75	0.53	2.81	0.53	Agree
5. There is a lack of accessible and complete instructional materials for AC operations.	3.13	0.35	2.88	0.68	2.94	0.62	Agree
6. Students are unable to study in detail the actual operation/configuration of real AC systems.	2.88	0.64	2.79	0.51	2.81	0.53	Agree
Dimension Average	**3.13**	**0.49**	**2.88**	**0.54**	**2.94**	**0.53**	**Agree**

Both teachers (M=3.13,SD=0.49) and students (M=2.88,SD=0.54) agreed on the existence of instructional limitations. Instructors reported slightly higher concern regarding the lack of trainer access (M=3.13) and instructional materials (M=3.13) compared to students (M=2.83 and M=2.88, respectively). Both groups strongly agreed that introducing a dedicated mock-up trainer would enhance practical learning (M=3.63 for teachers; M=3.33 for students; Overall M=3.41,SD=0.50).

Desired Component Content

Table 2 outlines the perceived importance of core components for inclusion in the trainer prototype.

Table 2 Perceived Importance of Air-Conditioning System Components

Component	Overall Mean (N=32)	Standard Deviation (SD)	Interpretation
Compressor	3.75	0.44	Very Important
Condenser	3.81	0.40	Very Important
Evaporator	3.81	0.40	Very Important
Thermal Expansion Valve	3.81	0.40	Very Important
Thermostat	3.78	0.42	Very Important
Controller / Main Switch	3.72	0.45	Very Important
High/Low-Pressure Gauges	3.72	0.45	Very Important
Copper Tubing Circuit	3.78	0.42	Very Important
Filter Drier	3.78	0.42	Very Important
Power Switch & Protection	3.78	0.42	Very Important
Relay / Capacitor Assembly	3.78	0.42	Very Important
Overall Mean	**3.78**	**0.42**	**Very Important**

All 11 listed components received "Very Important" ratings (M=3.72–3.81,SD=0.40–0.45), confirming that respondents prioritized a complete, fully functional refrigeration and electrical circuit for practical demonstrations.

Description of the Developed Mock-Up Trainer and Fabrication Costs

The physical trainer was fabricated as a open-frame mobile unit mounted on heavy-duty casters. The structure consists of a wooden display bench with a vertical mounting board. Real working components—including a hermetic compressor, finned-tube condenser, evaporator coil, capillary/expansion valve, filter drier, thermostat, fan motor assembly, dual pressure gauges, and a protective circuit breaker—were arranged logically to reflect the operational refrigeration cycle. Clear color-coded wiring and labeled connection terminals were installed to facilitate visual inspection and diagnostic measurement.

Figure 1 Physical Mock-Up Trainer Layout (Side, Front, and Top Views)

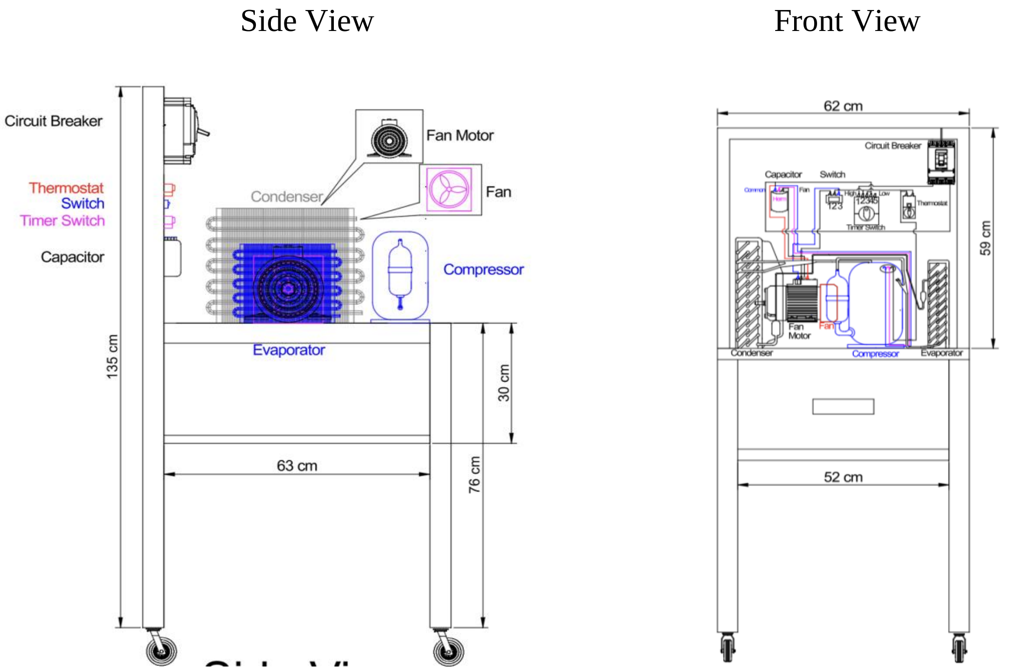
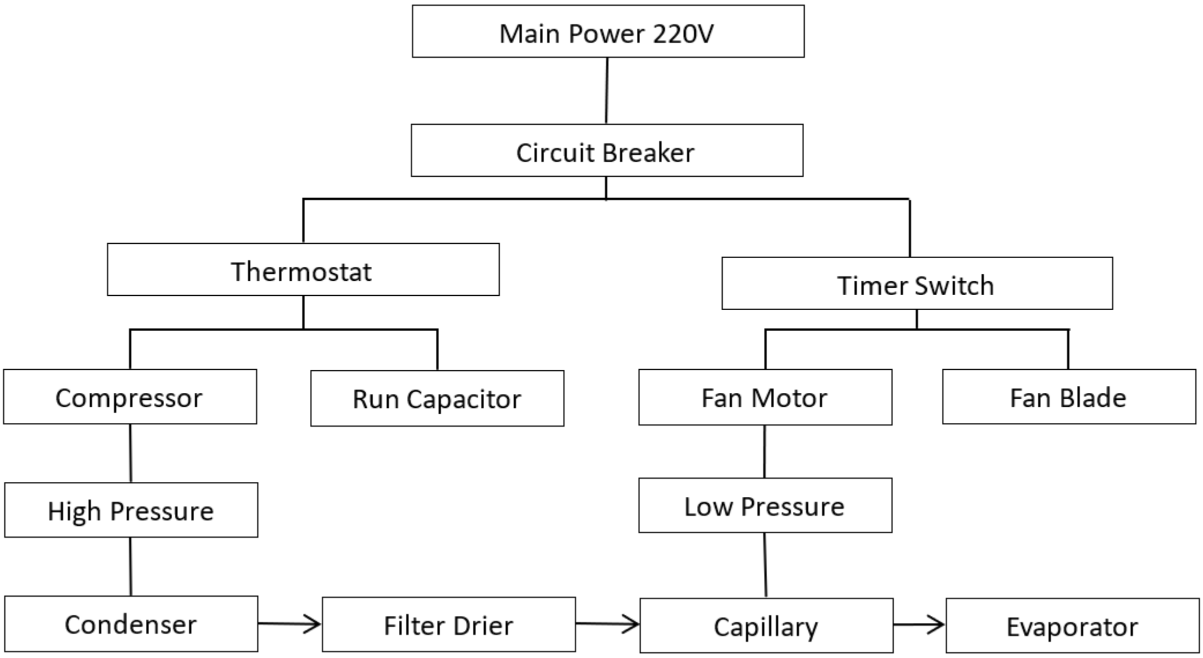


Figure 2 Schematic Wiring and Piping Layout of the Trainer



Estimated Fabrication Cost

To evaluate economic feasibility for TVET institutions, an estimated bill of materials and fabrication cost breakdown was compiled, as detailed in Table 3.

Table 3 Estimated Fabrication Cost Breakdown (in PHP / USD)

Item Description	Quantity / Specification	Estimated Cost (PHP)	Estimated Cost (USD)
Hermetic Compressor (1/2 HP)	1 unit (reconditioned/surplus)	3,500.00	$62.50
Condenser & Evaporator Coils	1 set with fan assembly	2,800.00	$50.00
Refrigerant Tubing & Expansion Valve	Copper lines, capillary tube, fittings	1,200.00	$21.40

Filter Drier & Pressure Gauges	High/Low manifold assembly	1,500.00	$26.80
Electrical Controls & Protection	Circuit breaker, thermostat, capacitor, relays, wires	1,800.00	$32.10
Frame Fabrication	Hardwood, plywood, caster wheels, fasteners	2,500.00	$44.60
Miscellaneous & Consumables	Refrigerant charging, solder, labels	1,200.00	$21.40
Total Estimated Cost		**PHP 14,500.00**	**~$258.80**

SME Validation of the Trainer Prototype

Table 4 summarizes the SME evaluation ratings (n=5) across technical accuracy, usability/labeling, and safety/durability.

Table 4 SME Evaluation Ratings for the Physical Trainer Prototype (n=5)

Dimension and Item Statement	**Mean**	**Standard Deviation (SD)**	**Interpretation**
A. Technical Accuracy			
1. The mock-up accurately represents real Air-Conditioning systems (Condenser, Compressor, Capillary Tube, Evaporator).	4.80	0.45	Excellent
2. Components used are similar to those in actual working Air-Conditioning systems.	4.60	0.55	Excellent
Dimension Average	**4.70**	**0.45**	**Excellent**
B. Usability and Labeling			
3. Setup, overall operation, and physical layout are easy to understand.	4.80	0.45	Excellent
4. Test points, connectors, controls, and components are clearly labeled and accessible.	5.00	0.00	Excellent
Dimension Average	**4.90**	**0.32**	**Excellent**
C. Safety and Durability			
5. Safe electrical wiring; protected connections; minimal exposure to electrical hazards.	4.40	0.55	Very Good
6. Physical structure and component mounting demonstrate durability for repeated training use.	4.40	0.55	Very Good
7. Wiring and piping are properly arranged, secured, and protected.	4.80	0.45	Excellent
Dimension Average	**4.53**	**0.42**	**Excellent**
Overall Prototype Validation Average	**4.71**	**0.38**	**Excellent**

The physical prototype received high ratings across all categories. Usability and labeling scored the highest (M=4.90,SD=0.32), highlighted by unanimous agreement on component accessibility (M=5.00,SD=0.00). Technical accuracy scored 4.70 (SD=0.45), confirming strong physical fidelity. Safety and durability scored 4.53 (SD=0.42). While expert evaluations confirm that the wiring layout aligns with basic electrical safety practices and low-voltage protection, formal industrial compliance certification (e.g., PEC, IEEE, ASHRAE Standard 15) was not tested and remains a subject for future laboratory inspection.

SME Validation of Instructional Materials

Table 5 reports the SME validation results for the accompanying instructional materials across content, clarity, and usefulness, directly answering Research Question 4.

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Table 5 SME Evaluation Ratings for Accompanying Instructional Materials (n=5)

Dimension and Criteria Item	Mean	Standard Deviation (SD)	Interpretation
A. Content Validity			
1. Information aligns with core RAC learning objectives and technical standards.	4.80	0.45	Excellent
2. Procedural steps for component identification and operation are accurate.	4.60	0.55	Excellent
Dimension Average	**4.70**	**0.45**	**Excellent**
B. Clarity			
3. Text explanations, diagrams, and labels are easy to comprehend for learners.	4.80	0.45	Excellent
4. Operational guidelines and safety precautions are clearly stated.	5.00	0.00	Excellent
Dimension Average	**4.90**	**0.32**	**Excellent**
C. Usefulness			
5. Manual effectively supports hands-on laboratory activities and guided instruction.	5.00	0.00	Excellent
6. Exercises facilitate practical understanding of air-conditioning operations.	4.80	0.45	Excellent
Dimension Average	**4.90**	**0.32**	**Excellent**
Overall Materials Validation Average	**4.83**	**0.31**	**Excellent**

The instructional materials achieved an overall validation mean of 4.83 (SD=0.31), with SMEs rating clarity (M=4.90) and practical usefulness (M=4.90) exceptionally high. Experts noted that step-by-step laboratory guides coupled with labeled physical components provide appropriate scaffolding for technical instruction.

DISCUSSION

The expert validation results (M=4.53–4.90) indicate that the prototype mock-up trainer and accompanying materials achieved strong technical and pedagogical quality within the evaluated panel. The high ratings for component accessibility (M=5.00) and instructional usefulness (M=5.00) suggest that mounting real components on an open mobile frame effectively supports visual demonstration and hands-on practice.

By integrating working parts—compressor, coils, expansion valve, and electrical controls—with clear labeling and step-by-step instructional guides, the trainer operationalizes key TVET pedagogical principles. Exposing operational components reduces extraneous cognitive load during initial learning, allowing students to map theoretical refrigeration principles directly onto physical hardware (Shakeel et al., 2022; Stapa & Mohammad, 2019).

Comparison with Prior R&D Studies

The findings align with similar developmental studies on TVET training equipment. Tagle (2023) developed the AirCoST trainer and reported that open-type operational trainers significantly enhance component familiarity. Baldos and Sabang (2025) designed a refrigeration fault simulator that demonstrated high expert validity and practical utility. Similarly, Delos Reyes et al. (2025) evaluated a car air-conditioning trainer aligned with TESDA competency standards, obtaining high acceptability ratings (M=3.8–4.0 on a 4-point scale). The positive SME evaluations in this study reinforce the established consensus that physical mock-ups utilizing authentic industrial components provide high technical fidelity for TVET instruction.

Alignment with Global Policy Frameworks

The development of low-cost, locally fabricated training equipment aligns directly with global sustainable development imperatives aimed at strengthening technical and vocational education infrastructure. Specifically, it advances Sustainable Development Goal (SDG) 4 (Quality Education, Targets 4.3 and 4.4) by providing functional training tools that support equitable access to relevant technical skills development (McGrath & Powell, 2016; Storonyanska et al., 2025). Furthermore, it contributes to SDG 8 (Decent Work and Economic Growth) by enhancing workshop equipment capacity to bridge the gap between vocational instruction and modern industrial practices (Chola & Kiplagat, 2025). Finally, this initiative supports SDG 9 (Industry, Innovation, and Infrastructure, Target 9.5), as the local fabrication of specialized equipment offers a scalable, cost-effective framework for modernizing TVET training facilities within resource-constrained environments (Edbais & Hossain, 2025; Küfeoğlu, 2022).

LIMITATIONS

Several limitations of this study should be recognized when interpreting the findings. First, the sample scope for the needs assessment was restricted to a localized group of 32 respondents in Misamis Occidental, which limits direct generalizability to broader national or international TVET contexts. Second, developmental validation relied on relatively small expert panels (n=4 for tool CVI and n=5 for prototype evaluation); while appropriate for initial developmental evaluation, compact panels can naturally inflate agreement metrics, occasionally yielding perfect Content Validity Indices (CVI=1.00) when evaluating straightforward items. Third, regarding the scope of evaluation, while the study successfully established prototype validity and pedagogical suitability according to expert review, it did not incorporate longitudinal tracking of student outcomes or quasi-experimental measurements of long-term skill acquisition. Finally, although the trainer was fabricated in accordance with fundamental low-voltage and educational safety guidelines, formal institutional certification against PEC or ASHRAE standards was not conducted.

RECOMMENDATIONS

Based on these findings, several actionable recommendations are proposed for practical implementation and future research. First, technical and vocational education and training (TVET) institutions are encouraged to consider adopting or replicating this low-cost mock-up trainer design to enhance hands-on laboratory experiences and supplement theoretical refrigeration and air-conditioning (RAC) instruction. Second, future research should deploy the physical trainer in active classroom environments using a pre-test/post-test experimental or quasi-experimental design to empirically assess student learning gains, task completion velocity, and long-term skill retention. Third, regarding safety and technical standards, subsequent design iterations should undergo rigorous formal electrical safety inspections, systematic refrigerant leak testing, and verified compliance testing against national and international engineering standards. Finally, researchers are encouraged to expand and replicate this developmental framework across multi-regional TVET centers and adapt the design for related technical disciplines, such as automotive air-conditioning and commercial refrigeration systems.

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