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Development and Evaluation of Innovative Car Air Conditioning Trainer

Nomer P. Delos Reyes, Dexter P. Fulo, Dion Rey D. Aliangan, Giovanni A. Alviar, Robin V. Bello, Adrian Kylle S. Damian, David A. Iturralde, Grant Mivic Kleian A. Jacinto, Miko Bry R. Locson, Ralph B. Mañada, Dante VI F. Orense, Chris John G. Peñaflor, Acelle Jade H. Rafanot, Jake R. Reyes, and Ivan D. Salvador

Bachelor of Science in Refrigeration and Air Conditioning Technology, College of Engineering and Technology, Zamboanga Peninsula Polytechnic State University

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ABSTRACT

This study developed and evaluated the Innovative Car Air Conditioning Trainer as an instructional prototype designed to enhance technical-vocational education in refrigeration and air conditioning technology. Guided by a developmental research design, the project progressed through three phases: design, construction, and evaluation. The trainer was conceptualized to integrate electrical protection devices, subsystem isolation switches, and digital monitoring instruments, thereby simulating the operational dynamics of an automotive air conditioning system. Fabrication involved the assembly of mechanical and electrical subsystems to replicate real-world RAC operations, while evaluation was conducted by faculty experts from the Bachelor of Science in Refrigeration and Air Conditioning Technology and Bachelor in Industrial Technology major in Heating, Ventilation, and Air Conditioning Technology (BIndTech HVACRT) programs at Zamboanga Peninsula Polytechnic State University. Using a structured survey instrument and four-point Likert scale, results revealed high levels of acceptability in terms of design, functionality, and instructional relevance, with mean ratings ranging from 3.8 to 4.0. Findings confirm that the trainer effectively bridges theoretical knowledge with hands-on practice, aligns with TESDA competency standards, and supports modular learning and fault simulation for enhanced student engagement. The study concludes that the prototype is both acceptable and effective as an instructional tool, with potential for replication, scaling, and further innovation to strengthen competency-based technical-vocational education.

Keywords: Innovative Car Air Conditioning Trainer, developmental research, refrigeration and air conditioning, instructional prototype, technical-vocational education

INTRODUCTION

Automotive air conditioning (AC) systems are indispensable for ensuring passenger comfort and driver safety, as they regulate cabin temperature, control humidity, and maintain air circulation. Beyond comfort, these systems contribute to road safety by reducing fatigue and enhancing driver concentration (Hidayat et al., 2023). Modern AC systems operate through thermodynamic processes such as vapor compression and heat exchange, and are increasingly integrated with electronic controls and microcontrollers managed by the vehicle's Electronic Control Unit (ECU), ensuring precise and efficient performance (Arif et al., 2017).

Despite the technological advancements in automotive AC systems, a critical gap persists in technical-vocational education, particularly in Refrigeration and Air Conditioning (RAC) Technology programs. While laboratory-based trainers have been shown to significantly improve student performance in technical courses, existing RAC laboratories lack specialized instructional equipment that simulates automotive AC systems. This absence limits students' opportunities to bridge theoretical knowledge with practical application, thereby constraining their readiness for industry demands.

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To address this gap, the present study introduces the Innovative Car Air Conditioning Trainer, a developmental prototype designed with an induction motor and functional controls to replicate the operational dynamics of automotive AC systems. The trainer provides a hands-on platform for Bachelor of Science in Refrigeration and Air Conditioning Technology (BSRACT) students to observe, manipulate, and evaluate system design and functionality. By integrating experiential learning into the curriculum, the trainer aims to enhance technical competencies, strengthen workforce readiness, and improve employability in the HVACR and automotive sectors.

LITERATURE REVIEW

Instructional materials and training devices are indispensable in technical-vocational education, particularly in refrigeration and air conditioning programs. Prior studies have consistently highlighted the challenges posed by inadequate laboratory equipment and instructional tools, which limit students' ability to develop manipulative skills and apply theoretical concepts in practice (Bajet Jr. et al., 2014; Guzman et al., 2015). Prototype trainers have been shown to bridge this gap by providing tangible platforms for learners to visualize, simulate, and test system operations, thereby enhancing comprehension and skill acquisition (Chavez et al., 2022).

The literature further underscores that instructional trainers are not merely supplementary but central to quality education. Their presence directly influences student performance, teaching effectiveness, and alignment with industry standards (Ramdi, 2020; Evangelista, 2020). Studies in industrial technology education emphasize that experiential learning through demonstrations, simulations, and trainer-based activities significantly improves outcomes compared to conventional lecture-based approaches (Purwanto et al., 2017; Siregar & Simatupang, 2020). Moreover, evaluation frameworks highlight the role of trainers not only as teaching aids but also as instruments for assessing instructional delivery and student competencies (Baral, 2015; Venkatesh, 2014; Renta-Davids et al., 2016).

Taken together, these findings reveal a consistent theme: instructional trainers are vital in bridging theoretical knowledge with practical application, fostering skill development, and ensuring workforce readiness. However, a notable gap remains in refrigeration and air conditioning laboratories, where no dedicated trainer exists for automotive air conditioning systems. Addressing this gap, the present study introduces the Innovative Car Air Conditioning Trainer, a developmental prototype integrating induction motor and motor control wiring to replicate the operational dynamics of automotive AC systems. Designed as an instructional material for technical-vocational education, the trainer aims to provide students with structured, hands-on learning opportunities, thereby enhancing their competencies, employability, and alignment with industry requirements.

To systematically guide the research and development process, the study adopted an Input–Process–Output (IPO) framework. The inputs comprised the review of related literature and studies, refrigeration cycle components (compressor, condenser, evaporator, capillary tube, filter drier), electrical parts (induction motor, motor control wiring, electronic display), and fabrication tools. The process followed sequential stages: design (schematic diagrams and layouts), construction (assembly and integration of components), testing (efficiency, durability, and safety), and evaluation (acceptability in terms of design and functionality as assessed by faculty experts). The output was the prototype Innovative Car Air Conditioning Trainer, serving as a pedagogical device that bridges theory and practice in automotive air conditioning education.

METHOD

Research Design

This study employed a developmental research design, which systematically integrates the processes of designing, constructing, and evaluating instructional innovations. Specifically, it focused on determining the level of acceptability of the Innovative Car Air Conditioning Trainer across four critical dimensions: design, functionality, and instructional relevance. The developmental approach was deemed most appropriate, as the primary objective was not only to produce a technically functional prototype but also to validate its

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pedagogical utility in refrigeration and air conditioning (RAC/HVAC) technology education. Guided by a structured design framework, the study ensured that the trainer's technical specifications were harmonized with instructional objectives and competency standards, thereby bridging theoretical knowledge with practical application. Through iterative evaluation and refinement, the research design facilitated both the validation of the trainer as an instructional device and the generation of empirical evidence supporting its effectiveness in enhancing student learning, faculty instruction, and industry readiness.

Participants and Locale

The evaluation phase was conducted at Zamboanga Peninsula Polytechnic State University (ZPPSU), specifically within the field of Refrigeration and Air Conditioning Technology (BSRACT) and Bachelor in Industrial Technology major in Heating, Ventilation, Air Conditioning, and Refrigeration Technology (BIndTech-HVART) programs. Faculty members specializing in refrigeration and air conditioning technology served as expert validators. Their professional expertise provided credible insights into the trainer's instructional relevance, safety, and acceptability.

The study was systematically implemented through three developmental phases to ensure rigor, functionality, and instructional relevance. In the Design Phase, the instructional framework and schematic diagrams—including wiring layouts—were conceptualized, while appropriate electrical and mechanical components such as safety breakers, magnetic contactors, digital thermostats, and indicator lights were carefully identified and aligned with TESDA competency standards in refrigeration and air conditioning servicing. The Construction Phase involved the fabrication of the prototype, integrating mechanical subsystems (compressor, evaporator, condenser fan) with electrical control and protection devices, alongside the installation of monitoring instruments (digital voltmeter, thermostat, indicator lights) to replicate real-world automotive AC operations, with emphasis on safety, durability, and usability for instructional purposes. Finally, the Evaluation Phase entailed the development and administration of a structured survey instrument to assess the trainer's acceptability and effectiveness in terms of design, functionality, safety, and instructional relevance, using a four-point Likert scale to capture expert responses and applying descriptive statistics (mean and standard deviation) to interpret results and determine the overall level of acceptability.

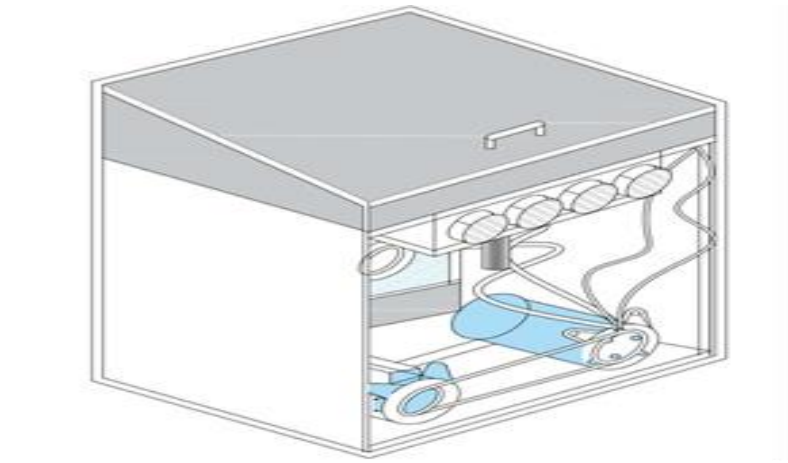
Ethical Considerations

The study adhered to institutional research ethics protocols. Participation of faculty evaluators was voluntary, with informed consent secured prior to data collection. Confidentiality of responses was maintained, and the evaluation process was conducted with transparency and academic integrity.

RESULTS AND DISCUSSION

Designing and Development of the Innovative Car Air Conditioning Trainer

Top View



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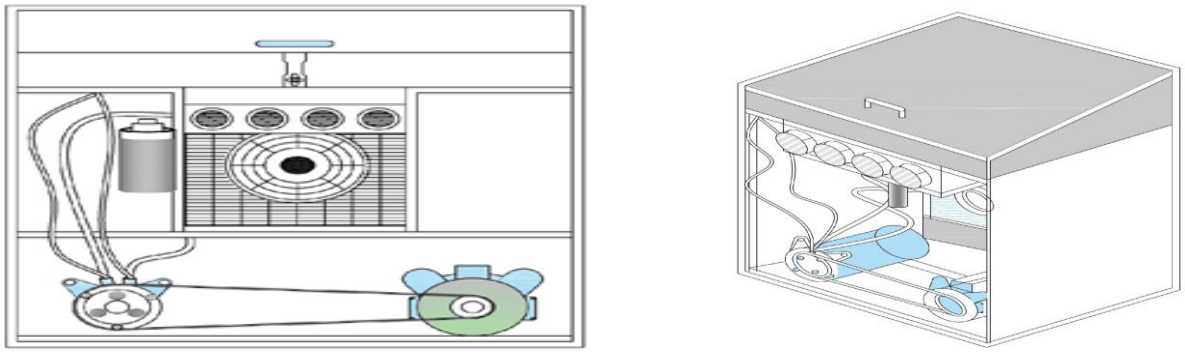

Front View Side View

Figure 1. Isometric View of the Innovative Car Air Conditioning Trainer

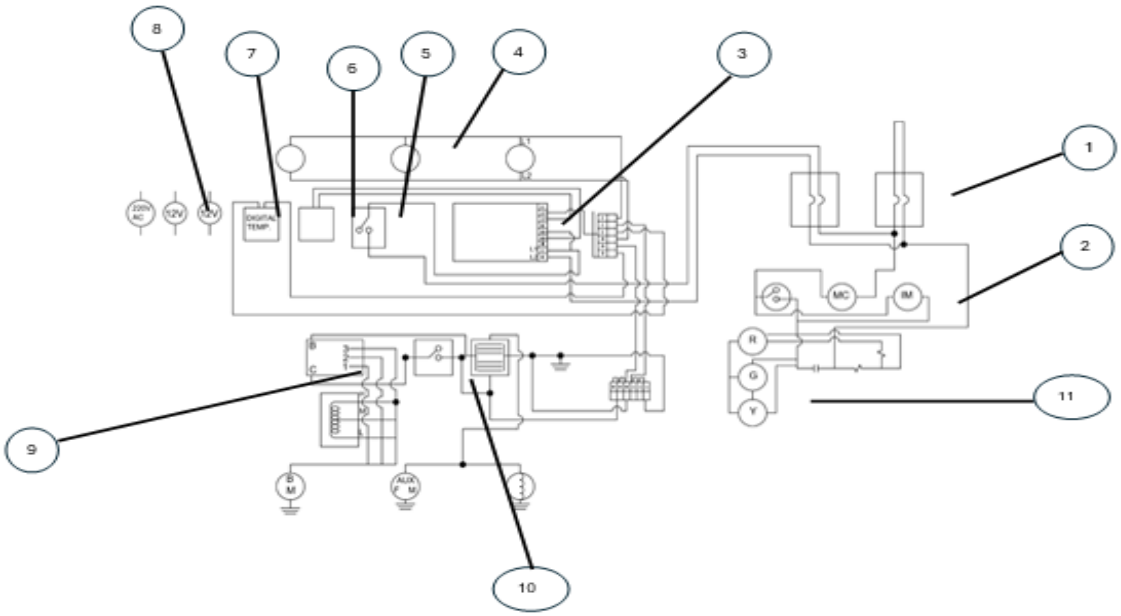

Figure 2. Wiring Diagram of the Control Interface of the Innovative Car Air Conditioning Trainer

Legend:

1- Safety Breaker
2- Magnetic Contactor
3- Power Supply
4- Exhaust Fan
5- Power Supply Switch
6- Digital Voltmeter
7- Digital Thermostat
8- Indicator Light
9- Evaporator Switch
10- Thermostat Switch
11- Indicator Light

The figure 2 presents the electrical schematic of the Innovative Car Air Conditioning Trainer, a pedagogical device designed to simulate the operational dynamics of an automotive air conditioning system. The wiring diagram integrates control, protection, and monitoring components to facilitate safe and interactive learning in technical-vocational education settings. It serves as a foundational reference for understanding the electrical interfacing of mechanical subsystems within the trainer.

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Component Description and Functional Integration

Legend No.	Component	Description and Instructional Role
1	Safety Breaker	Provides overcurrent protection for the entire circuit. It ensures safe operation and allows learners to understand fault isolation and circuit protection principles.
2	Magnetic Contactor	Acts as the main switching device for the compressor and fan motor. It introduces students to electromagnetic control and relay logic.
3	Power Supply	Delivers regulated electrical energy to the trainer. It models real-world automotive battery or alternator systems.
4	Exhaust Fan	Simulates heat dissipation in the condenser section. It reinforces airflow dynamics and thermal management concepts.
5	Power Supply Switch	Enables manual control of system activation. It supports basic switching theory and safety protocols.
6	Digital Voltmeter	Displays real-time voltage readings. It aids in diagnostics and electrical parameter monitoring.
7	Digital Thermostat	Regulates temperature thresholds within the evaporator section. It introduces learners to sensor-based control and feedback mechanisms.
8	Indicator Light	Signals system status (e.g., power ON, fault condition). It enhances visual feedback and troubleshooting exercises.
9	Evaporator Switch	Allows manual control of the evaporator fan. It supports subsystem isolation and targeted instruction.
10	Thermostat Switch	Enables or disables thermostat control. It facilitates comparative learning between manual and automated regulation.
11	Indicator Light	Secondary status indicator for specific subsystem activation

The wiring diagram underscores the relevance of the developmental study by concretely operationalizing the instructional objectives of the Innovative Car Air Conditioning Trainer. It bridges theoretical knowledge with practical electrical applications, thereby strengthening the integration of classroom concepts and hands-on practice. The schematic is deliberately aligned with TESDA competency standards in refrigeration and air conditioning servicing and diagnostics, ensuring that the trainer addresses industry-recognized skills and qualifications. Its modular design supports flexible learning pathways, fault simulation, and targeted instructional strategies that enhance student engagement and mastery of technical competencies. Moreover, the diagram demonstrates the safe and effective incorporation of control and protection devices, reinforcing the importance of safety and reliability in automotive AC systems. Collectively, these features validate the trainer's instructional design and substantiate its acceptability and effectiveness, as affirmed by expert evaluations from the faculty of the Bachelor of Science in Refrigeration and Air Conditioning Technology at Zamboanga Peninsula Polytechnic State University.

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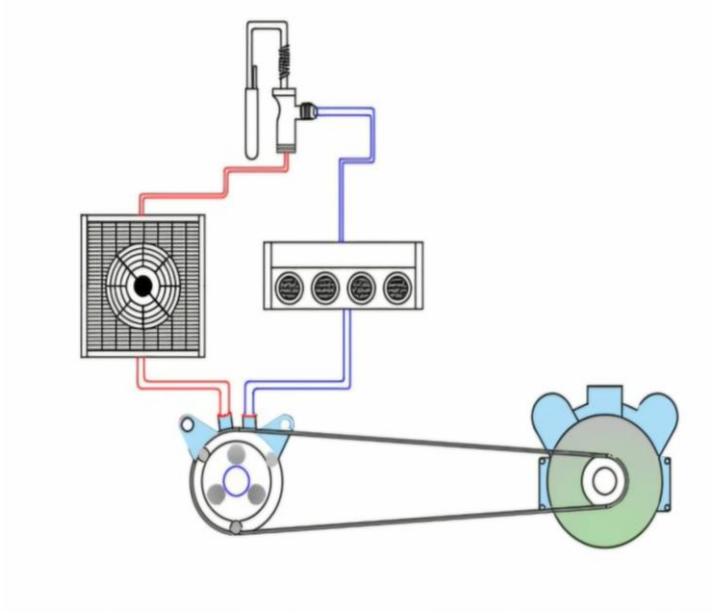

Figure 3. Mechanical Diagram

The figure 3 illustrates the mechanical layout and operational flow of the prototype car air conditioning trainer. This schematic serves as a pedagogical tool designed to simulate the actual working conditions of an automotive air conditioning (AC) system, enabling students to visualize and interact with its core components. The diagram integrates mechanical and thermodynamic principles, highlighting the refrigerant cycle and the role of each component in heat exchange and air modulation.

The diagram effectively illustrates the fundamental four-phase refrigeration cycle, which serves as the operational backbone of vapor-compression systems. In the compression phase, low-pressure refrigerant vapor is drawn into the compressor and mechanically compressed into a high-pressure, high-temperature vapor, thereby increasing its enthalpy and preparing it for heat rejection. This is followed by the condensation phase, wherein the high-pressure vapor passes through the condenser coils, releasing latent heat to the surrounding environment and undergoing a phase change into a high-pressure liquid. The expansion phase then occurs as the liquid refrigerant flows through the expansion valve or capillary tube, where a sudden pressure drop reduces its temperature and partially vaporizes the fluid, creating a low-pressure mixture. Finally, in the evaporation phase, this low-pressure refrigerant absorbs heat from the cabin or conditioned space as it circulates through the evaporator coil, thereby cooling the air while the refrigerant itself vaporizes back into a low-pressure gas, ready to re-enter the compressor. This cyclical process not only demonstrates the thermodynamic principles of heat transfer and phase change but also underscores the efficiency of vapor-compression systems in delivering controlled cooling for automotive and HVAC applications.

Evaluation Results on Instructional Relevance

Table 1. Instructional Relevance of the Innovative Car Air Conditioning Trainer in Terms of Design

Statement	Mean	Description
1. The trainer's overall design is visually clear and professionally structured.	3.75	Highly Acceptable
2. The arrangement of components (motor, gauges, wiring) is logically organized.	3.45	Highly Acceptable
3. The trainer's dimensions and frame provide adequate stability and usability.		

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4. The materials used in construction are durable and appropriate for instructional use.	3.50	Highly Acceptable
5. The design facilitates easy access to individual parts for demonstration and troubleshooting.	3.80	Highly Acceptable
	3.60	Highly Acceptable
Grand Mean	**3.84**	**Highly Acceptable**

Legend: 1.0-1.74- Not Acceptable; 1.75-2.49- Moderately Acceptable; 2.50- 3.24- Acceptable; 3.25-4.0- Highly Acceptable

The evaluation of the Innovative Car Air Conditioning Trainer in terms of design yielded a grand mean of 3.84, interpreted as Highly Acceptable, signifying that its physical and structural attributes were regarded by evaluators as meeting high standards of instructional usability and technical soundness. The highest rating was recorded for the durability and appropriateness of materials used (Mean = 3.80), affirming the reliability of its construction for repeated instructional use. Likewise, the trainer's overall design clarity and professional structure (Mean = 3.75) and its facilitation of easy access to individual parts for demonstration and troubleshooting (Mean = 3.60) were rated highly, underscoring its effectiveness in supporting hands-on learning and practical demonstrations. Slightly lower but still highly acceptable ratings were observed for the (Mean = logical arrangement of components 3.45) and the adequacy of dimensions and frame stability (Mean = 3.50), suggesting that while the trainer's layout and proportions were generally effective, minor refinements in component organization and frame design could further enhance usability and instructional efficiency. Overall, the findings validate the trainer's design as both pedagogically sound and technically robust, providing a safe, accessible, and durable platform for RAC/HVAC education. The consistently high acceptability ratings across indicators confirm its capacity to bridge theoretical instruction with practical demonstration, while iterative improvements in structural alignment and component arrangement may optimize its instructional value and replicability in broader educational contexts.

Table 2. Instructional Relevance of the Innovative Car Air Conditioning Trainer in Terms of Functionality

Statement	**Mean**	**Description**
1. The trainer accurately simulates the performance of an automotive air conditioning system.	4.0	Highly Acceptable
2. The controls and indicators respond consistently during operation.	3.8	Highly Acceptable
3. The trainer enables effective testing and diagnosis of system performance.	4.0	Highly Acceptable
4. The wiring and electrical configuration function reliably during repeated use.	3.8	Highly Acceptable
5. The trainer demonstrates refrigerant flow and pressure levels clearly through gauges.	3.8	Highly Acceptable
Grand Mean	**3.88**	**Highly Acceptable**

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Legend: 1.0-1.74- Not Acceptable; 1.75-2.49- Moderately Acceptable; 2.50- 3.24- Acceptable; 3.25-4.0- Highly Acceptable

The assessment of the Innovative Car Air Conditioning Trainer in terms of functionality yielded a grand mean of 3.88, interpreted as Highly Acceptable. This outcome demonstrates that the trainer effectively fulfills its intended role as a simulator of automotive air conditioning systems, with evaluators recognizing its accuracy in replicating system performance (Mean = 4.0) and its capacity to support effective testing and diagnosis (Mean = 4.0). The trainer's controls and indicators and wiring configuration were also rated highly acceptable (Mean = 3.8 each), reflecting consistent operational reliability during repeated use. Similarly, the clear demonstration of refrigerant flow and pressure levels through gauges (Mean = 3.8) affirms its instructional utility in visualizing key system processes. Collectively, these findings validate the trainer's technical robustness and pedagogical relevance, confirming that it provides a dependable, interactive platform for competency-based learning in refrigeration and air conditioning education. While minor refinements in control responsiveness and electrical configuration could further optimize performance, the overall high acceptability underscores the trainer's effectiveness as a functional instructional innovation.

Table 3. Instructional Relevance of the Innovative Car Air Conditioning Trainer in Terms of Instructional Relevance

Statement	**Mean**	**Description**
1. The trainer effectively bridges theoretical concepts with practical applications**.**	4.0	Highly Acceptable
2. The trainer enhances students' understanding of automotive air conditioning systems**.**	3.8	Highly Acceptable
3. The trainer supports faculty in delivering interactive and competency-based instruction**.**	4.0	Highly Acceptable
4. The trainer improves learners' troubleshooting and diagnostic skills**.**	4.0	Highly Acceptable
5. The trainer contributes to preparing students for industry challenges and job readiness	3.8	Highly Acceptable
Grand Mean	**3.92**	**Highly Acceptable**

Legend: 1.0-1.74- Not Acceptable; 1.75-2.49- Moderately Acceptable; 2.50- 3.24- Acceptable; 3.25-4.0- Highly Acceptable

The evaluation of the Innovative Car Air Conditioning Trainer in terms of instructional relevance produced a grand mean of 3.92, which is interpreted as Highly Acceptable. This result highlights the trainer's significant pedagogical value in effectively bridging theoretical knowledge with practical application in refrigeration and air conditioning (RAC/HVAC) education. The highest ratings (Mean = 4.0) were attributed to its ability to integrate theory with practice, support faculty in delivering interactive and competency-based instruction, and enhance learners' troubleshooting and diagnostic skills, thereby affirming its role in strengthening problem-solving and technical competencies. Slightly lower but still highly acceptable ratings (Mean = 3.8) were noted for its contribution to deepening student understanding of automotive air conditioning systems and preparing learners for industry challenges and job readiness, suggesting that while the trainer is impactful, further refinement and broader evaluation could enhance its long-term employability outcomes. Overall, the findings confirm that the prototype serves as a pedagogically sound instructional model, enriching both student learning and faculty teaching practices. Its interactive, hands-on approach aligns with contemporary educational frameworks that emphasize experiential learning and competency development, with high acceptability across

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all indicators validating its relevance as an instructional innovation. At the same time, the results point to opportunities for expanded testing, industry integration, and curriculum alignment to maximize its effectiveness in preparing graduates for professional practice in the HVACR sector.

DISCUSSION

The findings affirm that the trainer successfully operationalizes its instructional objectives by bridging theoretical knowledge with hands-on practice. The high acceptability ratings validate the prototype's pedagogical value, demonstrating its effectiveness in simulating real-world automotive air conditioning systems.

The trainer's modular design, which allows subsystem isolation and fault simulation, was recognized as a significant innovation for technical-vocational education. This feature supports active learning strategies, enabling students to engage in diagnostic exercises and performance testing that mirror industry practices. Moreover, the integration of digital monitoring instruments (voltmeter and thermostat) provides learners with immediate feedback, reinforcing competencies in electrical diagnostics and sensor-based control systems.

Alignment with TESDA competency standards further strengthens the trainer's relevance, ensuring that graduates are industry-ready and capable of meeting national certification requirements. The positive evaluation from expert faculty underscores the trainer's potential as a scalable instructional tool, suitable for replication in other institutions and adaptable for broader HVACR training applications.

The results demonstrate that the Innovative Car Air Conditioning Trainer is both acceptable and effective as an instructional prototype. Its design and functionality not only meet academic and industry expectations but also contribute to sustainable and competency-based technical-vocational education. The trainer's validated instructional design supports its integration into RAC curricula, thereby advancing innovation and skill development in the Zamboanga Peninsula and beyond.

CONCLUSION

The study successfully designed, constructed, and evaluated the Innovative Car Air Conditioning Trainer as a developmental instructional prototype for refrigeration and air conditioning technology education. The trainer demonstrated high levels of acceptability in terms of design, functionality, safety, and instructional relevance, as validated by expert faculty evaluators. Its integration of electrical protection devices, subsystem isolation switches, and digital monitoring instruments effectively bridged theoretical knowledge with practical application, thereby enhancing the pedagogical value of the prototype. The findings affirm that the trainer aligns with TESDA competency standards, supports modular and competency-based learning, and contributes to the advancement of technical-vocational education in the Zamboanga Peninsula.

RECOMMENDATIONS

Based on the study's results and conclusions, several strategic recommendations are advanced to maximize the instructional and developmental value of the prototype trainer. First, instructional integration is encouraged by incorporating the trainer into laboratory courses in refrigeration and air conditioning technology to reinforce student competencies in diagnostics, system operation, and safety practices. Second, replication and scaling across technical-vocational institutions is recommended to broaden its instructional impact and promote standardized competency-based training nationwide. Third, should be pursued through the integration of advanced features such as microcontroller-based digital controls, automated fault simulation, and data logging capabilities to enrich the learning experience. Fourth, further research is necessary continuous improvement, particularly longitudinal studies to assess the trainer's effectiveness in enhancing student performance and employability, alongside comparative analyses with traditional instructional methods. Finally, **policy support** from institutions and government agencies is vital to sustain innovation, ensure programmatic sustainability, and strengthen industry readiness within technical-vocational education.

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Conflict of Interest Statement

The authors declare that there are no conflicts of interest, whether financial, professional, or personal, that could have influenced the conduct, outcomes, or reporting of this study. The research was carried out independently, and all interpretations and conclusions are solely those of the authors.

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