IGNATIAN
INTERNATIONAL JOURNAL FOR MULTIDISCIPLINARY RESEARCH
www.icceph.com
ISSN 2984-9942

DEVELOPMENT AND EVALUATION OF MICROCONTROLLER-BASED SENSOR TRAINER: BASIS FOR LEARNER'S LABORATORY MANUAL

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https://doi.org/10.5281/zenodo.20314260

ABSTRACT

This study developed and evaluated a microcontroller-based sensor trainer as an instructional tool for the Electronic Products Assembly and Servicing (EPAS) strand under the Technical-Vocational-Livelihood (TVL) track in the Philippines. The trainer featured programmability, wireless connectivity, input/output sensor ports, and an LCD display. A developmental and descriptive research design was employed, with 15 respondents comprising five EPAS teachers, five TESDA trainers, and five industry practitioners evaluating the device. The trainer underwent technical performance testing for all features, followed by acceptability and instructional effectiveness assessments using validated researcher-made questionnaires (CVI range: 0.925-0.95; Cronbach's α: 0.738-0.779). Results showed the trainer achieved "Very High" acceptability in functionality (M=4.53) and effectiveness (M=4.58), with "High" reliability (M=4.48). Instructional effectiveness across 12 dimensions received an overall "Very High" rating (M=4.64). The trainer demonstrated consistent performance during three-day stress testing. A user's manual and eight learning activity sheets were developed to support classroom implementation. The findings support the integration of sensor-based trainers in competency-based electronics education.

Keywords: *microcontroller-based sensor trainer*, *TVL-EPAS*, *instructional effectiveness*, *technical-vocational education*, *sensor integration*

INTRODUCTION

Across the globe, rapid technological advancement in automation and electronics has transformed workforce skill requirements. As industries adopt smart systems and IoT applications, there is increasing demand for technicians trained not only in theory but in hands-on, system-based skills. The World Economic Forum (2020) predicts that over half of all workers will require significant upskilling in technology within the next five years. Educational systems, therefore, must provide learners with opportunities to engage in practical, real-world applications of their knowledge.

Sensor trainers, particularly those integrated with microcontrollers, have emerged as effective tools to meet this challenge. These trainers allow students to simulate industrial scenarios by using real sensors and programmable systems. According to Smith and Johnson (2020), sensor trainers promote critical thinking, improve retention, and prepare learners for automation tasks by bridging the gap between theoretical lessons and real-world application. Gonzalez and Rivera (2021) further emphasized that integrating sensor trainers into technical education enhances student engagement by providing interactive learning experiences that closely simulate industrial environments.

In the Philippines, the Technical-Vocational-Livelihood (TVL) track, specifically the Electronic Products Assembly and Servicing (EPAS) strand under the K to 12 curriculum, emphasizes practical skills in electronics, automation, and control systems (Department of Education, 2016). However, many schools still rely on traditional lecture-based instruction, with limited exposure to modern training tools. This gap hinders students from acquiring competencies aligned with industry expectations. Dela Cruz and Mariano (2021) noted that high-quality instructional materials contribute significantly to learner competency development, especially in subjects requiring mastery of hands-on technical skills.

Microcontroller-based sensor trainers offer a solution by making abstract concepts tangible. Students can interact with components such as ultrasonic, PIR, infrared, and temperature sensors, enabling them to understand sensing technology and system integration. Anderson et al. (2022) found that students trained using sensor-based instructional tools demonstrated a 40% improvement in troubleshooting skills compared to those following conventional lecture-based instruction. Despite their potential, the use of sensor trainers in TVL education remains limited due to factors such as usability, cost, and lack of structured teaching resources (Rodriguez, 2020).

This study is anchored in David Kolb's (1984) Experiential Learning Theory (ELT), which emphasizes learning through direct experience, reflection, and active experimentation. The trainer encourages students not only to assemble and test circuits but also to observe outcomes, analyze results, and refine their understanding through active experimentation, aligning with the ELT principle that practical experience leads to meaningful learning.

Research Objectives

The main purpose of the study was to develop and evaluate the microcontroller-based sensor trainer as a basis for the learner's laboratory manual. Specifically, the study aimed to:

1. Design and develop a sensor trainer with the following technical features: programmable, wireless connectivity, input sensor ports, output sensor ports, and liquid crystal display.
2. Test the technical features including programmability, wireless connectivity, input sensor ports response and accuracy, output sensor ports functionality, and LCD performance.
3. Evaluate the acceptability of the sensor trainer in terms of functionality, effectiveness, and reliability.
4. Determine the instructional effectiveness of the sensor trainer across 12 dimensions: ease of use, accuracy, reliability, user interface, data interpretation, integration, maintenance, durability, sensitivity, power efficiency, portability, and performance.
5. Develop a user's manual and learning activity sheets for the sensor trainer.

METHODOLOGY

Research Design

This study employed a developmental and descriptive research design, combining both approaches to address evaluation and creation aspects. Descriptive research assessed the status of the developed instructional tool focusing on functionality, effectiveness, reliability, and instructional value (Gay et al., 2012). Developmental research guided the systematic design, development, and refinement of the microcontroller-based sensor trainer (Richey & Klein, 2007). A quantitative approach was applied using researcher-made survey instruments.

Respondents of the Study

The study involved 15 qualified respondents from three sectors: five Electronics Products Assembly and Servicing (EPAS) teachers from the Department of Education (DepEd), five professional electronics practitioners, and five certified TESDA EPAS trainers. This diverse group was chosen for their expertise in both theoretical instruction and practical application of electronics.

Setting and Limitations

The study was conducted in classroom and training center settings in Negros Occidental, Philippines. The trainer was equipped with input sensors (ultrasonic, PIR, infrared, and temperature with I2C LCD) and output devices (buzzer, LED indicator, and relay module). The study was limited to basic interfacing concepts and was influenced by the instructional methods used by facilitators and the learners' prior experience with microcontrollers, excluding advanced applications or industrial deployment.

Instrumentation

A researcher-made survey instrument was used, structured into two main parts. Part I gathered demographic information. Part II evaluated functionality, effectiveness, and reliability. Lawshe's Content Validity Index (CVI) was applied with 10 subject matter experts. The CVI for functionality was 0.925, effectiveness 0.95, and reliability 0.925. Reliability was established through pilot testing with 30 respondents using Cronbach's Alpha: functionality/effectiveness/reliability questionnaire achieved α=0.738 (95% CI: 0.567-0.852), and instructional effectiveness questionnaire achieved α=0.779 (95% CI: 0.646-0.871).

Data Gathering Procedure

The researcher sent formal letters to the Division Office of Negros Occidental and to school principals for approval. Upon obtaining permissions, the instrument was administered to respondents. Numerical responses were recorded, organized, and encoded for statistical analysis using mean and standard deviation.

Data Analysis

Descriptive statistics (mean and standard deviation) were used to analyze acceptability and instructional effectiveness. Mean scales: 1.00-1.49 (Very Low), 1.50-2.49 (Low), 2.50-3.39 (Average), 3.50-4.49 (High), and 4.50-5.00 (Very High).

Cost Analysis

The total material cost was ₱1,790.00, with labor at 40% (₱716.00), resulting in a total production cost of ₱2,506.00 per unit.

RESULTS

Technical Performance Testing

The sensor trainer underwent comprehensive performance testing. Table 1 presents the programmability test results.

Table 1. Test Trials on Programmability of the Sensor Trainer

Activity	Trial 1 Status	Trial 2 Status	Trial 3 Status	Observations
Uploading Sensor-Output Program	Successful	Successful	Successful	Uploads completed without errors
Code Modification and Re-uploading	Functional	Functional	Functional	Code changes reflected instantly
Program Execution (LCD, Sensor, Outputs)	Working	Working	Working	No bugs, crash, or delay observed

The sensor trainer underwent comprehensive performance testing. Table 2 presents the Wi-Fi and Bluetooth connectivity test results.

Table 2. Wi-Fi and Bluetooth Connectivity Test Results

Connectivity Type	Trial 1	Trial 2	Trial 3	Status
Wi-Fi Connection	Connected Successfully	Connected Successfully	Connected Successfully	Stable, No Dropouts
Wi-Fi Data Transfer	Smooth, No Delay	Smooth, No Delay	Smooth, No Delay	Reliable for Monitoring/Upload
Bluetooth Pairing	Successful	Successful	Successful	Consistent Device Pairing
Bluetooth Data Transfer	No Lag or Drop	No Lag or Drop	No Lag or Drop	Stable and Responsive

The sensor trainer underwent comprehensive performance testing. Table 3 presents the sensor port response and accuracy evaluation results.

Table 3. Sensor Port Response and Accuracy Evaluation

Sensor Type	Port No.	Measured Output	Response Time	Accuracy	Functional?
Ultrasonic Sensor	Port 1	5-100 cm range	~250 ms	±1.5 cm	Yes
PIR Sensor	Port 2	Motion Detection	~500 ms	3-meter range	Yes
Infrared Sensor	Port 3	Obstacle Proximity	~350 ms	Consistent Reflection	Yes
Temp Sensor (DHT11)	Port 4	26-32°C (varied room)	~1 second	±1°C	Yes

The sensor trainer underwent comprehensive performance testing. Table 4 presents the output port functionality test results.

Table 4. Output Port Functionality Test

Output Device	GPIO Pin	Trigger Source	Response Time	Observations
Buzzer	GPIO 25	PIR and IR Sensors	~200 ms	Loud, quick tone emitted
LED Indicator	GPIO 26	PIR Sensor	~150 ms	Instantly illuminated
Relay Module	GPIO 27	Temp > 30°C	~300 ms	Switched 5V fan properly

The sensor trainer underwent comprehensive performance testing. Table 5 presents the liquid crystal display (LCD) performance test results.

Table 5. Liquid Crystal Display (LCD) Performance Test

Test Factor	Observation	Result
Initialization	Successful upon startup	✓
Real-time Updates	Temperature and Distance refreshed live	✓
Screen Clarity	Visible in low and bright light	✓
Stability	No flicker or lag during testing	✓

Acceptability of the Sensor Trainer

The sensor trainer underwent comprehensive performance testing. Table 6 presents the acceptability of the sensor trainer in terms of functionality.

Table 6. Acceptability of Sensor Trainer in Terms of Functionality

FUNCTIONALITY	M	SD	Interpretation
The sensor trainer is easy to use and operate.	4.73	0.47	Very High
The components of the trainer function properly and efficiently.	4.60	0.51	Very High
The trainer has sufficient features to support learning and practical applications.	4.53	0.65	Very High
The design and layout of the trainer enhance usability.	4.40	0.51	High
The trainer is user-friendly for both students and instructors.	4.53	0.51	Very High
The trainer provides clear and accurate sensor readings.	4.60	0.50	Very High
The materials and components used are durable and long-lasting.	4.40	0.51	High

FUNCTIONALITY	M	SD	Interpretation
The trainer is adaptable for different instructional settings.	4.40	0.51	High
As a Whole	4.53	0.52	Very High

The sensor trainer underwent comprehensive performance testing. Table 7 presents the acceptability of the sensor trainer in terms of effectiveness.

Table 7. Acceptability of Sensor Trainer in Terms of Effectiveness

EFFECTIVENESS	M	SD	Interpretation
The sensor trainer enhances students' understanding of sensor-based technology.	4.67	0.47	Very High
The device facilitates hands-on learning in electronics and technology subjects.	4.47	0.51	High
The trainer is an effective supplement to theoretical instruction.	4.60	0.50	Very High
The device provides real-world applications relevant to industry standards.	4.73	0.43	Very High
The trainer improves problem-solving and technical skills.	4.40	0.51	High
The device effectively demonstrates various sensor functionalities.	4.67	0.50	Very High
The instructional guide and materials provided with the trainer are helpful.	4.53	0.50	Very High
The trainer allows students to practice troubleshooting sensor-related issues.	4.60	0.50	Very High
As a Whole	4.58	0.53	Very High

The sensor trainer underwent comprehensive performance testing. Table 8 presents the acceptability of the sensor trainer in terms of reliability.

Table 8. Acceptability of Sensor Trainer in Terms of Reliability

RELIABILITY	M	SD	Interpretation
The sensor trainer meets the needs of students and instructors.	4.60	0.50	Very High
Users are satisfied with the overall design and performance.	4.47	0.51	High
The trainer is suitable for educational institutions offering electronic and technology courses.	4.67	0.47	Very High
The device maintains consistent performance over time.	4.60	0.50	Very High
The trainer operates with minimal errors and malfunctions.	4.33	0.63	High
The components remain functional even with frequent use.	4.47	0.51	High
The device is designed for long-term usability in training programs.	4.40	0.51	High
Technical support and maintenance requirements are minimal.	4.33	0.73	High
As a Whole	4.48	0.58	High

Instructional Effectiveness

The sensor trainer underwent comprehensive performance testing. Table 9 presents the instructional effectiveness of the sensor trainer.

Table 9. Instructional Effectiveness of Sensor Trainer

Effectiveness Dimension	M	SD	Interpretation
Ease of Use	4.73	0.61	Very High
Accuracy	4.60	0.51	Very High

Effectiveness Dimension	M	SD	Interpretation
Reliability	4.53	0.51	Very High
User Interface	4.67	0.63	Very High
Data Interpretation	4.73	0.43	Very High
Integration	4.53	0.65	Very High
Maintenance	4.67	0.61	Very High
Durability	4.53	0.65	Very High
Sensitivity	4.67	0.47	Very High
Power Efficiency	4.67	0.47	Very High
Portability	4.73	0.43	Very High
Performance	4.73	0.43	Very High
As a Whole	4.64	0.53	Very High

DISCUSSION

Technical Performance

The performance test results (Tables 1-5) demonstrated that the microcontroller-based sensor trainer successfully met all design specifications. The programmability tests (Table 1) confirmed that the ESP32-WROOM-32E microcontroller consistently accepted and executed code modifications without errors or delays. This finding aligns with Hrovat et al. (2023), who reported that ESP32-based IoT devices facilitate active learning and support educators in the teaching process.

The wireless connectivity test results (Table 2) demonstrated that the sensor trainer's built-in Wi-Fi and Bluetooth capabilities performed reliably across all trials, with stable connections and no data dropouts. This finding aligns with the work of Hrovat et al. (2023), who reported that ESP32-based IoT devices facilitate active learning and support educators in the teaching process by enabling seamless wireless communication. The successful pairing of Bluetooth with mobile and desktop devices and the smooth Wi-Fi data transfer confirm the trainer's capacity to support modern instructional delivery modes, including remote monitoring and over-the-air programming. This feature is particularly relevant in the context of Industry 4.0, where wireless communication is essential for IoT applications (Goldsmith, 2005). The ability to upload code wirelessly without physical connection to a computer enhances the flexibility of classroom instruction and reduces dependency on wired infrastructure, addressing a common limitation in resource-constrained technical-vocational settings (Rodriguez, 2020).

The sensor input ports (Table 3) demonstrated high accuracy, with the ultrasonic sensor achieving ±1.5 cm accuracy and the temperature sensor maintaining ±1°C precision. These results support Patel et al.'s (2020) finding that students trained using sensor-based tools retained and applied technical knowledge more effectively than those using traditional methods.

The output ports (Table 4) responded quickly to sensor triggers, with response times ranging from 150-300ms, enabling real-time feedback essential for instructional applications. The output ports demonstrated quick and accurate responses to sensor-triggered signals, with response times ranging from 150 to 300 milliseconds across the buzzer, LED indicator, and relay module. These findings support the assertions of Anderson et al. (2022), who found that students trained using sensor-based instructional tools demonstrated significant improvements in troubleshooting skills. The immediate illumination of the LED indicator upon PIR sensor activation and the loud, clear tone emitted by the buzzer provide students with real-time auditory and visual feedback, reinforcing the cause-and-effect relationships essential for understanding control systems and automation logic (Patel et al., 2020). The relay module's ability to switch a 5V external load without voltage drop or delay demonstrates the trainer's capacity to interface with real-world actuators, bridging the gap between theoretical instruction and practical industrial applications. This functionality aligns with the competency-based education (CBE) approach emphasized in the EPAS NC 2 curriculum, where students must demonstrate mastery of output device control as part of their NC II certification requirements (Department of Education, 2016; Lopez et al., 2021).

The LCD performance test (Table 5) confirmed the I2C LCD's consistent performance across all test conditions, confirming its suitability as a real-time data visualization tool for instructional purposes. The successful initialization on startup, live updates of temperature and distance readings, and clear visibility under both low and bright lighting conditions address concerns raised by Ramirez and Tolentino (2023) regarding the practicality of instructional technology in diverse classroom environments. The absence of flickering or lag during prolonged testing supports the reliability findings, indicating that students can depend on the display for accurate real-time monitoring without frustration or technical interruption. The LCD's ability to provide immediate visual feedback without requiring an external computer enhances the trainer's portability and self-contained nature, allowing it to be used in various instructional settings, including workshops, laboratories, and even outdoor demonstrations (Gonzalez & Rivera, 2021). This feature supports Kolb's (1984) Experiential Learning Theory by enabling students to observe, reflect, and conceptualize sensor data in real time, thereby deepening their understanding of embedded systems and microcontroller-based applications.

The seamless integration of wireless connectivity (Table 2), output actuation (Table 4), and LCD display (Table 5) creates a cohesive learning environment where students can observe the complete signal chain—from sensor input to wireless transmission to output response to visual display. This integrated approach is consistent with the findings of Garcia et al. (2021), who emphasized that modular educational devices with programmable flexibility support interdisciplinary learning and align well with modern curriculum needs. The combination of these features enables instructors to design progressively challenging activities, starting from basic sensor reading and display to advanced wireless monitoring and remote actuation. This scalability enhances the trainer's long-term usability across different year levels and competency levels within the TVL-EPAS strand, maximizing the return on investment for educational institutions (Santos & Reyes, 2019).

When compared with existing microcontroller-based trainers, such as the PIC microcontroller-based control trainer developed by Ghaleb et al. (2012) and the Embedded System Laboratory Kit proposed by Moazzami (2015), the current sensor trainer offers distinct advantages in terms of wireless connectivity and modular sensor interfacing through TRRS connectors. While earlier trainers focused primarily on wired connections and basic input-output operations, the ESP32-based trainer's built-in Wi-Fi and Bluetooth capabilities enable remote monitoring and data logging, features that are increasingly essential in modern electronics education (Hrovat et al., 2023). The use of standardized TRRS audio jacks for both input sensors and output devices simplifies connections, reduces the risk of wiring errors, and promotes hands-on experimentation without soldering, addressing a key limitation identified in earlier trainer designs (Garcia et al., 2021).

The positive results for wireless connectivity, output functionality, and LCD performance have direct implications for instructional delivery in the TVL-EPAS strand. Teachers can design activities where students program the trainer to send sensor data to a cloud dashboard via Wi-Fi, receive commands via Bluetooth from a mobile device, or trigger output devices based on LCD-displayed thresholds. These real-world scenarios prepare students for industry expectations where remote monitoring, wireless control, and data visualization are standard practices (World Economic Forum, 2020; Lopez et al., 2023). Furthermore, the reliable performance of these features reduces cognitive load on both instructors and students, allowing them to focus on learning objectives rather than troubleshooting equipment failures (Smith & Johnson, 2020).

Acceptability

The functionality rating (M=4.53, Very High) indicates strong user acceptance, particularly for ease of use (M=4.73). This finding is consistent with Davis's (1989) Technology Acceptance Model, where perceived ease of use directly influences technology adoption. The slightly lower ratings for design layout and adaptability (M=4.40) suggest opportunities for ergonomic improvements, like Rodriguez's (2020) observation that teacher support and training significantly affect successful implementation.

The effectiveness rating (M=4.58, Very High) was strongest for real-world applications relevant to industry standards (M=4.73). This aligns with Lopez et al. (2021), who noted that industry standards necessitate students acquire strong troubleshooting techniques and automation proficiency. The trainer's ability to bridge theory and practice supports Kolb's (1984) Experiential Learning Theory, as students engage in concrete experience through direct sensor manipulation.

The reliability rating (M=4.48, High) indicates generally consistent performance with minor areas for improvement. Users expressed highest confidence in the trainer's suitability for educational institutions (M=4.67) and its ability to meet student and instructor needs (M=4.60). However, minimal errors/malfunctions (M=4.33) and technical support requirements (M=4.33) received relatively lower ratings, suggesting that component quality improvements could enhance long-term reliability.

Instructional Effectiveness

The overall instructional effectiveness rating (M=4.64, Very High) across all 12 dimensions demonstrates the trainer's strong pedagogical value. The highest ratings for ease of use, data interpretation, portability, and performance (all M=4.73) indicate that the trainer effectively removes technical barriers to learning. This finding supports Papastergiou's (2009) emphasis on integrating interactive tools into technical education to improve engagement and learning outcomes.

The high ratings for user interface (M=4.67) and data interpretation (M=4.73) suggest that students can focus on learning sensor concepts rather than struggling with equipment operation. This is consistent with Brown et al.'s (2022) demonstration that interactive sensor-based learning led to a 50% increase in knowledge retention over six months.

The maintenance (M=4.67) and power efficiency (M=4.67) ratings indicate that the trainer is suitable for extended classroom use without frequent intervention, addressing concerns raised by Ramirez and Tolentino (2023) about the practicality of instructional technology in resource-constrained settings.

Conclusions

1. The design and development of the sensor trainer successfully incorporated all intended technical features: programmability via ESP32 microcontroller and Arduino IDE, wireless connectivity through Wi-Fi and Bluetooth, four TRRS input sensor ports (ultrasonic, PIR, infrared, temperature), three TRRS output ports (buzzer, LED, relay), and an I2C LCD for real-time data display. The trainer proved user-friendly, functional, and effective for teaching sensor-based technologies.
2. The technical testing confirmed that all features operated according to specifications. Programmability allowed instant code reflection without resets. Wireless connectivity maintained stable connections across all trials. Input sensors demonstrated response times of 250-1000ms with high accuracy (ultrasonic ±1.5

cm, temperature ±1°C). Output ports responded to within 150-300ms. The LCD performed reliably with clear visibility under varying light conditions. Three-day stress testing showed no failures or degradation.

3. The sensor trainer demonstrated "Very High" acceptability in functionality (M=4.53) and effectiveness (M=4.58), with "High" reliability (M=4.48). Users particularly praised ease of use (M=4.73) and real-world industry relevance (M=4.73). Areas for improvement include design layout, material durability, and component longevity under frequent use.
4. The instructional effectiveness across 12 dimensions received an overall "Very High" rating (M=4.64). The trainer excelled in ease of use, data interpretation, portability, and performance (all M=4.73), making it highly suitable for classroom and laboratory instruction. The device effectively enhanced student understanding of sensor-based technology and supported hands-on learning.
5. A comprehensive user's manual and eight structured learning activity sheets were successfully developed, incorporating feedback from expert evaluators. These materials provide step-by-step guidance for setup, operation, troubleshooting, and learning activities aligned with EPAS NC 2 competencies.

Recommendations

For Education Program Supervisor (EPS) in TLE. The EPS should consider integrating the sensor trainer into the EPAS NC 2 curriculum to align with current industry standards and technological trends. The trainer can serve as a model tool for updating instructional content, ensuring learners acquire relevant skills in electronics and automation.

For EPAS Students. Students are encouraged to maximize use of the sensor trainer during laboratory activities. The device offers meaningful hands-on learning that enhances understanding of sensor technologies, improves technical competencies, and prepares students for real-world applications in the electronics industry.

For EPAS Teachers. Teachers should adopt the sensor trainer as part of their teaching strategy to improve instructional delivery. The trainer promotes active learning, increases student engagement, and effectively bridges theory and practice. Teachers should provide feedback for future improvements and participate in continuous training on innovative instructional tools.

For TESDA Trainers. TESDA trainers should incorporate sensor trainers into technical training programs. The device serves as an effective tool for outcomes-based training and assessment by providing learners with real-time sensor interaction and troubleshooting experience. Trainers should collaborate in refining training methodologies using such tools to maintain instructional relevance and quality.

For Future Researchers. Future research should investigate the long-term effectiveness and impact of the sensor trainer through comparative studies involving other instructional devices or expanded evaluations in different learning environments. Cost-efficiency analysis and student performance outcomes over time should also be explored.

For the Researcher. This study provides a foundation for instructional innovation in technical-vocational education. Further research should validate and improve the design and usability of the sensor trainer across broader educational contexts. The findings may serve as a reference for developing or evaluating similar sensor-based instructional materials.

Compliance with Ethical Standards

The researcher obtained informed consent from all participants prior to their involvement in the study. Participants were fully informed about the study's objectives, procedures, potential benefits, and any foreseeable risks, ensuring voluntary participation based on clear understanding. Participants were given the opportunity to ask questions and withdraw from the study at any time without negative consequences. Confidentiality and anonymity were strictly maintained throughout the study. All personal information, responses, and performance scores were kept confidential and used solely for research purposes. Identifying details were anonymized to protect participant privacy, and data were reported in aggregate form. The study adhered to the principle of non-maleficence, ensuring no harm, discomfort, or disadvantage was inflicted upon participants. Data protection measures prevented unauthorized access, modification, or exposure of sensitive information. The study complied with ethical guidelines set by the Philippine Health Research Ethics Board (PHREB), following principles of respect for persons, beneficence, non-maleficence, and justice. No conflict of interest exists in the conduct of this study. Plagiarism was strictly avoided, and no bias was present in the interpretation of findings. Results were used purely for academic purposes. No AI tools were used in the analysis or writing of this manuscript beyond basic word processing functions.

Acknowledgments

The researcher expresses sincere gratitude to the Division Office of Negros Occidental for granting permission to conduct this study. Sincere appreciation is extended to the EPAS teachers, TESDA trainers, and industry practitioners who served as respondents and evaluators. The researcher acknowledges the valuable guidance of the research advisers and the support of the institution's research ethics committee. Gratitude is also expressed to the technical experts who validated the research instruments and to the pilot test participants whose feedback enhanced the quality of this study.

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APA Citation:

Armonio, J. R. (2026). DEVELOPMENT AND EVALUATION OF MICROCONTROLLER-BASED SENSOR TRAINER: BASIS FOR LEARNER'S LABORATORY MANUAL. Ignatian International Journal for Multidisciplinary Research, 4(5), 2084–2099. https://doi.org/10.5281/zenodo.20314260

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