Photovoltaic System Trainer

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Abstract: The main focus of the study was the development of a Photovoltaic System Trainer. It was designed and constructed as an instructional device to provide students with a more engaging and experiential learning of the photovoltaic system. This study utilized developmental and descriptive methods of research. For developmental method, processes were used like planning, designing, lay-outing, constructing, assembling, pre-testing and revising, final product testing and evaluating. While the descriptive method was evaluated in terms of product quality in performance efficiency, durability, reliability, maintainability, and conformance; and for the acceptability like design, functional suitability, security, usability, and portability were also evaluated. A research-made instrument was formulated and administered to twenty-five experts for quality product evaluation and seventy-five respondents for its acceptability. The result showed that the trainer has a dual-powered device, interactive learning, and can extend battery operation as its technical features can reinforce the teaching and learning processes; for quality evaluation, the overall results showed in terms of performance efficiency, durability, reliability, maintainability, and conformance were very good. Further, for acceptability evaluation, the overall results in terms of design, functional suitability, security, usability, and portability were very highly acceptable. The users manual was developed to guide the users on the product specifications, features, parts and functions, operating procedures, maintenance, dos and don'ts, and troubleshooting guide. The activity sheets were beneficial to both students and teachers in learning processes. Finally, the trainer is ideal for the BSIT Electronics/Electrical and BTLED Industrial Arts curriculum and conducting the National Competency Assessment by TESDA.

Keywords: Photovoltaic System Trainer, Microcontroller, Interactive Learning, Quality, Acceptability, Developmental and Descriptive Research.

I. Introduction

Access to instructional technology and equipment is critical for high-quality education. Countries such as Japan, Australia, Taiwan, China, Korea, and India have achieved technological modernization and innovation by aligning their technical educational systems with contemporary technological advancements. This alignment has contributed significantly to improving the skills of their learners, showcasing the importance of integrating modern technology into education [13].

Experiential learning is a teaching method where children learn by doing and experiencing things firsthand. Unlike traditional classes where students just listen to a teacher, this method gets them actively involved. It helps them solve problems and create real projects, making learning more interesting and helping them remember the information better.

A prime example of experiential learning is the use of manipulatives, which are physical teaching tools that engage students visually and physically. When used effectively, manipulatives help students problem-solve, reason, and transfer their understanding [5]. Teachers offer materials and clear instructions, enabling students to interact with the resources and ask questions during the lesson, which enriches their learning experience.

In university-level electronics and electricity courses, students gain knowledge and skills in constructing devices that incorporate diverse components essential for creating and deploying renewable energy systems like solar power. A comprehensive grasp of electrical circuit principles is crucial for success in these courses. Electrical and Electronic Technology is a major field in Industrial Technology, where students are taught competencies ranging from basic to advanced levels in electrical circuits.

However, according to [14], many educators still rely on self-contained books or modules to deliver lesson content. This reliance on traditional teaching methods, especially in mechanical and engineering topics, can fail to impart lesson content effectively, leading to students losing interest and perceiving the subject matter as challenging [15].

Innovative solutions like trainers have been developed to address these learning challenges and the scarcity of learning materials. A cutting-edge Photovoltaic System Trainer has been designed to address the inadequacy and scarcity of learning materials in the classroom. This trainer empowers students to thoroughly grasp essential concepts, including the interpretation and analysis of schematic diagrams, the intricate interconnection of wiring within circuits, adept utilization of multimeters for precise measurements, troubleshooting techniques, and a profound understanding of photovoltaic systems' complex operations.

This study's nature was considered to address the instructional training needs of students. By integrating advanced trainers and simulators into the curriculum, educators can provide more effective and engaging learning experiences, ultimately enhancing students' skills and understanding of electronics and electricity, particularly in renewable energy systems like photovoltaic technology

Objectives of the Study

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The main objective of the study was the development of a Photovoltaic System Trainer.

Specifically, it aimed to:

1. design and construct a Photovoltaic System Trainer with the following technical features:
   a. dual-powered device,
   b. interactive learning, and
   c. extend battery operation;
2. evaluate the product quality in terms of the following dimensions:
   a. performance efficiency,
   b. durability,
   c. reliability,
   d. maintainability, and
   e. conformance;
3. evaluate the acceptability as to its:
   a. design,
   b. functional suitability,
   c. security,
   d. usability, and
   e. portability;
4. formulate its user manual and activity sheets.

II. Methods

Research Design

This study used both developmental and descriptive research methods. Developmental research, as explained by [8], involves creating and improving new materials, products, or processes based on existing knowledge. In this study, it involved developing a Photovoltaic System Trainer through various stages like planning, designing, constructing, and testing.

Descriptive research, according to [1] and [5], focuses on understanding the characteristics of a population or phenomenon by collecting and analyzing data. In this study, it involved using a survey to assess the quality of the trainer in terms of performance, durability, reliability, serviceability, and overall design, to determine how well it meets various criteria.

Design Criteria

The design criteria include technical features, product quality, product acceptability, and Instructional capabilities.

Technical Features

As an innovative device, the development of the Photovoltaic System Trainer has the following technical features:

a. The trainer is a dual-powered device that can be powered in two ways: through a solar panel or AC power. This dual-power feature ensures efficient battery charging for smooth operation.

b. The trainer is interactive and easily configured depending on the learning activity's demands.

c. The trainer has an extended battery operation, including a microcontroller technology circuit that automatically manages charging. It also has a current booster circuit and a capacitor bank. These parts team up to control and increase the amount of electric current from the battery.

Product Quality

The trainer shows the following product quality aspects:

a. Performance Efficiency. It produces and harnesses solar energy, manages energy storage, and gives reliable results for educational and practical applications.

b. Durability. It can handle things like wear and tear changes in temperature and humidity and still work well over time.

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c. Reliability. It's designed to function seamlessly during training sessions and practical demonstrations, ensuring users can trust its performance for accurate and consistent results.

d. Maintainability. It can be repaired, and parts are locally available if needed.

e. Conformance. It's designed and calibrated in accordance with industry norms, ensuring that it meets the prescribed requirements during operation.

Product Acceptability

a. Design. It has an interface designed to monitor input/easily output power, voltage, and current during solar energy simulation.

b. Functional Suitability. It effectively and accurately simulated the operational functionalities facilitating hands-on learning experiences.

c. Security. It has a protocol implemented to safeguard against risks such as tour case lock, tamper-resistance tour case, and key control systems from unauthorized access and operation.

d. Usability. It's easily and effectively performed, and users can navigate the trainer's features to comprehensively learn and actively engage with photovoltaic system concepts and practical applications with ease and effectiveness.

e. Portability. Size and weight were appropriate for classroom use. Its easily transported and utilized across various educational or training environments.

Instructional Capabilities

The trainer shows the following instructional capabilities:

a. The trainer is designed suited to the Fundamental Electrical and Electronics Technology course subject.

b. The trainer is designed to be suited to BSIT Electronics and Electrical, BTLED IA Electronics and Electricity subject, EPAS curriculum, and training activities.

c. The trainer is designed to enhance the student's skills in assembling and disassembling the Photovoltaic System setup.

d. The Trainer will be used for CHMSU BSIT- Electronics, BSIT- Electrical, and BTLED Industrial Arts.

Design, Plan, Preparation, and Fabrication

It involves the development of a Photovoltaic System Trainer, materials used, tools and equipment, construction procedure, operating procedure, production flow, pre-testing, revision made, final testing, and construction time frame.

Development of Photovoltaic System Trainer

The development of Photovoltaic System Trainer consists of the wiring diagram, orthographic view with major parts perspective view are shown in Figure 1-6 respectively.

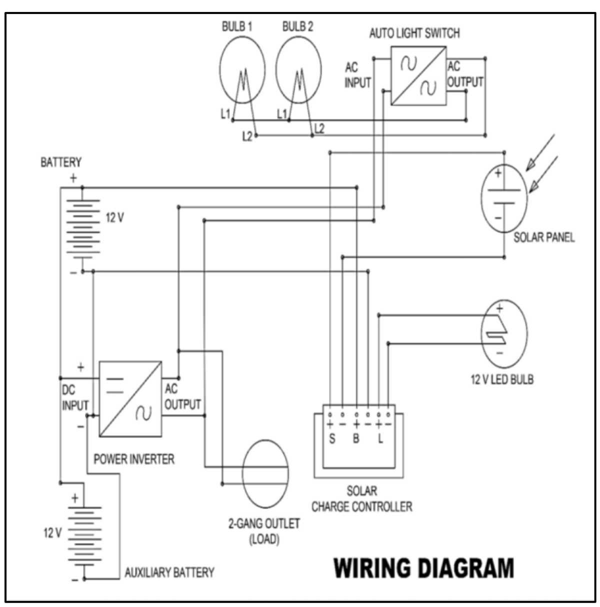

Fig. 1 Wiring Diagram of the Photovoltaic System Trainer

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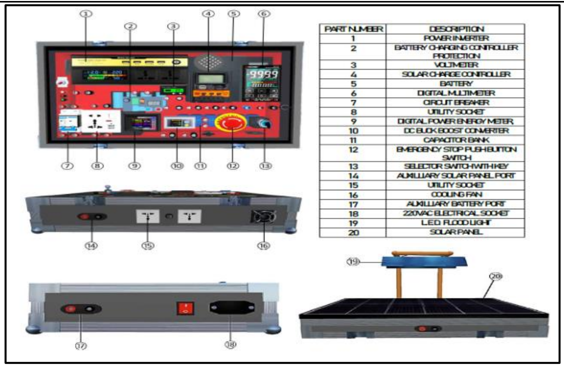

Fig. 2 Orthographic View with Major Parts of the Photovoltaic System Trainer

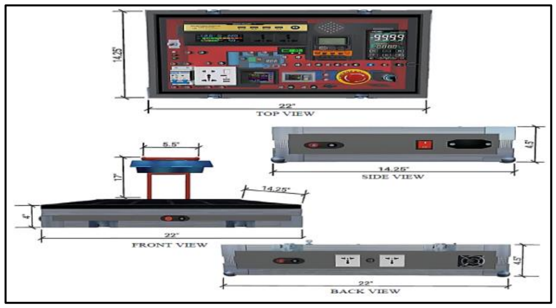

Fig. 3 Orthographic View with Dimensions

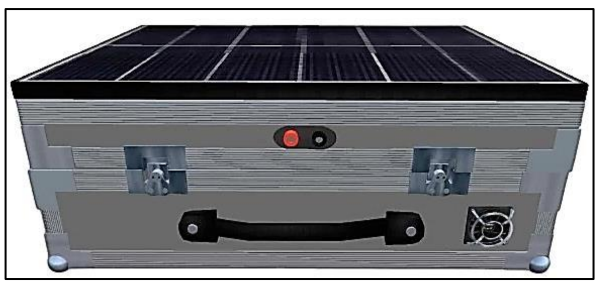

Fig. 4 Isometric Front View of the Photovoltaic System Trainer in Close Position

Fig. 5 Isometric Back View of the Photovoltaic System Trainer in Close Position

Fig. 6 Isometric View of the Photovoltaic System Trainer in Close Position

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Fig. 7 Isometric View of the Photovoltaic System Trainer in Set-up Position

Interrelationship of Parts

Figure 8 presents the block diagram of the photovoltaic system trainer, which shows the interrelationship of parts. According to [19], the interrelationship of parts within a system determines its functionality and performance.

The interrelationship of parts within the photovoltaic system trainer is essential for its efficient operation. The solar panel harnesses radiant energy from the sun and converts it into electrical energy. This electrical energy is channeled through a solar anti-backflow ideal diode constant current circuit, which protects against potential backflow when integrating additional auxiliary solar panels for upgrades. Subsequently, the current booster circuit enhances the electrical signal for a strong current flow and feeds it to the solar charge controller. This stage efficiently and effectively maximizes the charging process for the battery. It can also supply power to a 12V LED floodlight, providing additional light for solar panel charging when sunlight is unavailable.

Furthermore, the trainer can also be operated using a 220V AC source. This is connected to the battery charger, then to the primary battery, and fed to a capacitor bank for storage. The DC buck-boost converter regulates the voltage and current output from the capacitor bank and feeds it to the battery charging controller for protection. It is also an external DC input source for devices like LED lights, cooling fans, Bluetooth speakers, and DC electronic circuit projects. It also has an input terminal for an auxiliary battery, reinforcing continuous operation if the primary battery becomes weak or extends the trainer's operation. The digital voltmeter serves as an indicator of the battery's voltage output.

In addition, the main power on/off switch is used to open and close the circuit operation, which is directly connected to the primary battery and power inverter. The emergency on/off switch protects the main circuit from damage if problems are encountered, like a shorted connection.

Lastly, the trainer has a power inverter to change DC voltage to AC voltage output. It is an external input source that needs AC voltage power for televisions, computers, laptop chargers, radio cassettes, electric hand drills, electric fans, LED, and incandescent bulbs. Moreover, it is connected to a circuit breaker for its protection. The digital power energy meter serves as an indicator of the output signals.

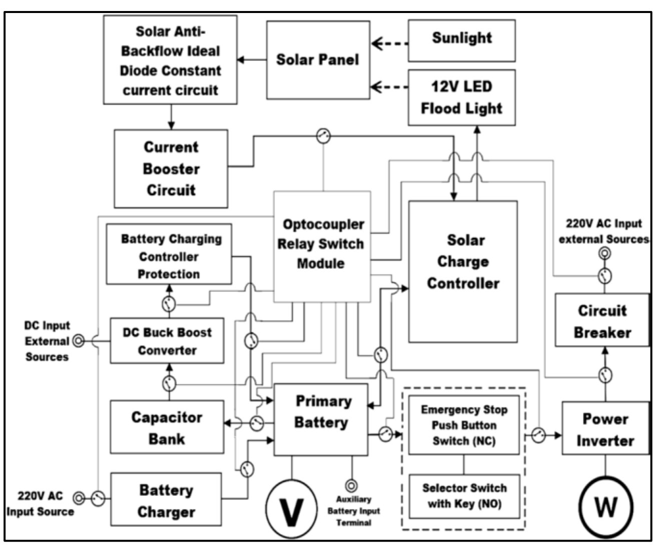

Fig. 8 Block Diagram of Photovoltaic System Trainer Showing the Interrelationship of Parts

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Materials Used

Table 1 shows the bill for materials, which includes quantity, unit, specification, unit cost, and total costs.

Table 1Bill of Materials

Qty	Unit	Description of Material	Unit Cost	Total Cost
1	pc	Utility socket with USB	350.00	350.00
1	pc	Solar panel 20watts	1300.00	1,300.00
1	pc	Solar inverter 500 watts	3500.00	3500.00
1	pc	Solar charge controller PWM	500.00	500.00
1	pc	LED Light 25 watts	180.00	180.00
1	set	500-farad capacitor bank circuit	2,200.00	2,200.00
1	set	Current booster circuit	280.00	280.00
6	pcs	Optocoupler relay switch module	129.00	774.00
1	pc	Battery charging controller protection	184.00	184.00
2	pcs	Anti-Backflow Ideal Diode Constant current circuit	160.00	320.00
1	pc	10A battery charger	850.00	850.00
1	set	Lifepp4 battery 12v 18ah	3500.00	3500.00
1	pc	Digital voltmeter	230.00	230.00
1	pc	Digital power energy meter	328.00	328.00
1	pc	DC buck-boost converter	428.00	428.00
1	pc	Digital multimeter	1100.00	1100.00
3	pcs	LED strip light	150.00	450.00
1	pc	Circuit breaker	100.00	100.00
1	pc	Emergency Stop Push Button Switch	80.00	80.00
1	pc	Selector Switch with Key	202.00	202.00
2	pcs	Cooling fan blower with fan grill	160.00	320.00
10	feet	PVC Tube	80.00	80.00
1	Bottle	Ferric Chloride	35.00	35.00
2	pcs	Convenience outlet	100.00	200.00
31	pcs	Banana socket	16.00	496.00
10	meter	Gauge 16 stranded wire (RED and BACK)	32.00	320.00
2	sets	Banana plug test leads	457.00	914.00
1	pc	Briefcase handle	100.00	100.00
4	pcs	Briefcase butterfly lock	95.00	380.00
1	pc	Combinational pin Lock	60.00	60.00
4x4	ft	½ Marine Plywood	400.00	400.00
4x4	ft	Formica	400.00	400.00
200	ml	Wood Glue	120.00	120.00
2	pcs	Rubber Footing	15.00	30.00
12	Ft.	Aluminum Corner	240.00	240.00
18x18	inch	¼ Rubber Matting	45.00	45.00
30	pcs	Revits	1.00	30.00
2	cans	Spray Paint	100.00	200.00
4	meters	Soldering Lead 60/40	16.00	64.00
Total Cost of Materials				**Php 21,290.00**

Tools and Equipment

Table II shows the tools and equipment used and their functions.

Table II Tools and Equipment and their Functions

Tools	Function
Steel tape measure	Used for measuring the dimensions of the project
Hack saw or cutting disc	Used for cutting metals
Wood saw	Used to cut plywood
Screw Driver	Used to tighten and loosen screws
Mechanical hammer	Used to pound unnecessary form
Vernier caliper	Used to measure the inner and outer dimensions of the
Drill bits	Tool attached to an electric drill for boring holes
Soldering Iron	Used to solder wires
Hand Riveter	Used to rivets for attaching parts
12V Mini drill	Used to drill holes in the P.C.B. where electronic component inserted for soldering process
Equipment	
Electric grinder	Used for sanding and cutting plywood for the project
Jig saw	Used to cut the acrylic glass
Electric drill	Used for boring holes
Multi – Tester	Used to test and measure the power supply voltage and circuit connections of the trainer.

Construction Procedure

The construction procedure of the Photovoltaic System Trainer is shown below.

Case construction

1. Prepare all materials, tools, and equipment needed to construct the casing.
2. Measure the dimension requirement of the casing on the plywood using the steel tape measure.
3. Cut the plywood based on the dimension requirement.
4. Assemble the casing and cover Formica on the assembled casing to make it clean and presentable.
5. Install the aluminum brackets and hinges of the casing.
6. Make sure that the casing is ready for the project circuit installation.

Current Booster and Capacitor Bank circuit module Assembling

1. Prepare the materials, tools, and equipment needed for constructing the Current Booster and Capacitor Bank circuit module circuit module.

2. Make a P.C.B. design of the circuit.

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3. Transfer the P.C.B. design using masking tape on the copper side of the 2x3 P.C.B.

4. Cut and remove the excess design of the masking tape using a paper cutter.

5.Soak the P.C.B. using ferric chloride for the etching process.

6. Clean the P.C.B. copper side with water and sandpaper.

7. Test the P.C.B. resistance for the leak or grounded connection.

8. Drill the P.C.B. using a mini drill 12v for component placement.

9. Solder all electronic components using a soldering iron.

10. Cut the excess electronic component's terminal using a side cutter plier.

11.Test the assembled circuit module using the solar panel and battery to see if it functions.

Final Product Assembly and Testing

1. Prepare all electronic modules for installation and wiring connections.

2. Install all the components in constructed cases using a screwdriver. The materials accordingly: power inverter, solar charge controller, battery, battery charger, solar panel, emergency stop push button switch, selector switch with key, digital power energy meter, circuit breaker, utility socket, voltmeter, digital multimeter, anti-backflow ideal diode constant current circuit, switches, LED light, connectors and circuit module assembly like capacitor bank, current booster circuit, battery charging controller protection, DC buck-boost converter and microcontroller.

3. Interconnect the internal wiring connection of the trainer.

4. Test the continuity of the wiring connection using a multimeter.

5. Test the trainer to see if it is functional in three ways. Data is shown in

Tables 4-6 respectively.

Operating Procedures

1. Begin by setting up or opening the training equipment in a suitable workspace.
2. Position the solar panel in an area with ample sunlight to maximize energy absorption.
3. Use lead wire connectors to assemble components as needed, ensuring secure connections.
4. Verify all connections using a multimeter to confirm proper installation and functionality.
5. Prior to activation, ensure that the circuit breaker is in the off position to prevent accidental activation.
6. Take note of safety signs indicating high voltage and adhere to all safety precautions while operating the equipment.
7. Once connections are confirmed, follow the guidance provided by the instructor to proceed with the operation.
8. Only switch on the circuit breaker after receiving approval from the instructor to ensure safe activation.
9. Monitor the charge controller panel to confirm the battery is charging actively.
10. Turn on the switch to deliver power to the connected load, and monitor power output accordingly.
11. When finished using the device, deactivate the circuit breaker and switch off the selector switch with a key to shut down the system safely.
12. Finally, disconnect the lead wires and carefully store all tools and equipment in their designated storage locations.

Production Flow

Figure 9 shows the workflow of the production process of the Photovoltaic System Trainer. Most of the operation involves fabricating a box using an electric grinder with a cutting disc to cut the plywood and Formica board based on the layout. Wood glue forms the box and attaches all accessories. An electric drill bores holes in the box to attach the corner brackets, handle, and lock. A riveter secures the rivets into necessary parts. Finally, a soldering iron is used to connect various components to the circuit, including the power inverter, solar charge controller, battery, battery charger, solar panel, emergency stop push button switch, key-operated selector switch, digital power energy meter, circuit breaker, utility socket, voltmeter, digital multimeter, anti-backflow ideal diode constant current circuit, switches, LED light, and connectors. The circuit module assembly includes a capacitor bank, current booster circuit, battery charging controller protection, DC buck-boost converter, and microcontroller, all placed according to the layout. After completing the assembly of all materials, the trainer undergoes pre-testing, followed by a

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more extensive assessment to ensure proper operation and functionality. Various issues may arise during this phase, prompting the researcher to identify and address the causes. This thorough examination ensures that the trainer operates according to its specified features. After assembling the various parts, necessary revisions are made to enhance the trainer's overall performance.

Following pre-testing and revisions, the final testing phase is initiated. Three configurations of the trainer are established for comparison: the basic photovoltaic system, the system with a current booster circuit and LED lights facing the solar panel, and the system with a microcontroller and a circuit module assembly. The researcher assesses the trainer's performance by simultaneously using a 25-watt LED light, a 40-watt fan, and a 45-watt 32-inch LED TV. These experiments are conducted precisely to evaluate the trainer's battery consumption and ability to extend battery operation.

Through analyzing and comparing these configurations, the researcher aims to determine the optimal working conditions for the trainer and unveil its effectiveness in extending battery operation. The development of the trainer reaches completion after undergoing phases of pre-testing, revision, and final testing. The process involves consulting with experts who provide valuable insights and utilizing researcher-designed survey questionnaires to assess various product quality dimensions and overall acceptability. This collaborative approach ensures a well-rounded evaluation and refinement of the trainer's features and performance.

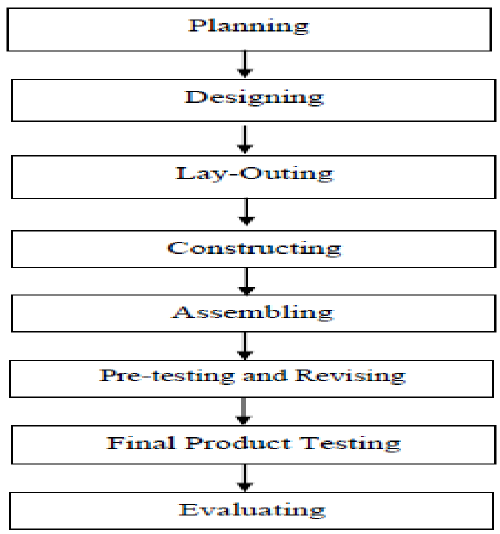

Fig. 9 Production Flow in Developing the Photovoltaic System Trainer

Pre-testing and Revisions Made

During the pre-testing, several problems were encountered, and the researcher determined the possible causes of the problems to ensure that the trainer would operate perfectly based on its technical features. Table III shows the problems encountered, possible causes, and revisions made during the pre-testing.

Table III Pre-testing and Revisions Made in the Construction of the Trainer

Problems Encountered	Possible Causes	Revisions Made
1. Limited primary battery storage	10 Ah battery	Additional 8Ah battery in parallel to the primary battery to increase the total capacity of the battery system to 18Ah.
2. Lack of protection against battery overcharging when voltage source using AC power input.	It can lead to overheating, degradation, and potentially hazardous conditions such as explosions.	Installed a relay protection circuit that automatically stops charging when the battery is fully charged.
3. Intermittent operation of Utility socket.	The utility socket was poorly installed, causing it to become a loose connection whenever an AC input source was plugged or unplugged.	The utility socket was changed to the suited one.
4. Slow charging and fast drain battery	Relay consumes power from the primary battery as an additional load when unused.	The wiring connections from the relay and key switch were reconnected to prevent the relay switch from operating when the trainer is turned off.

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Final Product Testing for Battery Consumption of the Trainer

Table IV-VI shows the results of the battery consumption of the trainer using three (3) configurations: the basic photovoltaic system, with a current booster circuit and LED lights facing to the solar panel, and with microcontroller and a circuit module assembly. Table VII is the overall result in the battery consumption. The researcher executed these three configurations utilizing a 25-watt LED light, a 40-watt fan, and a 45-watt 32-inch LED TV as the configuration of external input sources. These steps were meticulously executed, and the trainer's operation was evaluated in terms of battery consumption, including time duration, voltage level, and percentage.

Table IV Battery Consumption of the Basic Photovoltaic System

Time Duration (in minutes)	Voltage Level (Battery fully Charged 13.2V)	Percentage
0-5 mins.	13.2V	100%
6-10 mins.	13.1V	97%
11-15 mins.	13.0V	93%
16-20 mins.	12.9V	89%
21-25 mins.	12.8V	85%
Total 25 mins	**Ave. 13.0V**	**Ave. 92.8%**

Table IV presents the battery consumption of a basic photovoltaic system within a 25-minute testing duration. As recorded, the battery voltage gradually decreases from 13.2V to 12.8V, with a corresponding drop in battery percentage from 100% to 85%. The average voltage is 13.0V, with an average battery percentage of 92.8%. The discharge rate appears consistent, with approximately 0.1V dropped in voltage and a 2-3% decrease in battery percentage every 5 minutes. This consistency shows stable energy consumption during the test period.

Table V Battery Consumption of Trainer with Current Booster Circuit and LED Lights Directly Facing the Solar Panel

Time Duration (in minutes)	Voltage Level (Battery fully Charged 13.2V)	Percentage
0-5 mins.	13.2V	100%
6-10 mins.	13.2V	100%
11-15 mins.	13.1V	97%
16-20 mins.	13.0V	95%
21-25 mins.	13.0V	93%
Total 25 mins	**Ave. 13.1V**	**Ave. 97%**

Table V presents the battery discharge time of the trainer using a current booster circuit with LED lights directly facing the solar panel. The battery voltage remained relatively stable, with minor fluctuations between 13.2V and 13.0V. The battery percentage level stayed consistently high, with an average voltage of 13.1V and an average battery percentage of 97%. This shows that the trainer maintains its effective and efficiency.

Table VI Battery Consumption of Trainer with a Microcontroller and Circuit Module Assembly

Time Duration (in minutes)	Voltage Level	Percentage
0-5 mins.	13.2V	100%
6-10 mins.	13.2V	100%
11-15 mins.	13.2V	100%
16-20 mins.	13.1V	98%
21-25 mins.	13.1V	97%
Total 25 mins	**Ave. 13.16V**	**Ave. 99%**

Table VI presents the battery discharge time of the trainer with a microcontroller and the integration of the circuit module assembly. It was observed that the voltage level remains constant at an average value of 13.16V throughout the given time duration. It was concluded then that utilizing a microcontroller and circuit module assembly were the best circuit designs to maintain the battery's performance and operation.

Table VII Over-all Result of the Battery Consumption Across Three Configurations

Duration of Battery to Drain (in minutes)	Standard Photovoltaic System (Voltage / Percentage)	Trainer with Current Booster Circuit with LED Lights (Voltage / Percentage)	Trainer with Microcontroller and Circuit Module Assembly (Voltage / Percentage)
0-5 mins.	13.2V / 100%	13.2V / 100%	13.2V / 100%
6-10 mins.	13.1V / 97%	13.2V / 100%	13.2V / 100%
11-15 mins.	13.0V / 93%	13.1V / 97%	13.2V / 100%
16-20 mins.	12.9V / 89%	13.0V / 95%	13.1V / 98%
21-25 mins.	12.8V / 85%	13.0V / 93%	13.1V / 97%
Total 25 mins	**Ave. 13.0V / 92.8%**	**Ave. 13.1V / 97%**	**Ave. 13.16V / 99%**

Table VII presents the general results of the battery discharge time across different trainer configurations. Comparing the three setups, it's evident that integrating microcontrollers and circuit module assembly can significantly improve the trainer's efficiency and extend its battery operation. In the basic photovoltaic system, the battery experienced a more significant voltage drop, about an average of 13.0V, and a lower overall battery percentage of 92.8%. When the trainer has a current booster circuit with LED

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lights directly connected facing the solar panel, the battery voltage remains relatively stable with a value of 13.1V for most of the test duration, with only a slight decrease of the battery percentage average of 97%. Nevertheless, it still seems to positively impact battery performance, as indicated by the stable voltage levels and high average battery percentage. This setup is more energy-efficient compared to the basic photovoltaic system setup.

Moreover, when a microcontroller and circuit module assembly add the trainer, the battery voltage and percentage level remain consistently high throughout the test, averaging 13.16V and 99%. Thus, integrating these microcontroller and circuit module assemblies appear to be more effective in maintaining battery performance for longer operation when used in the trainer. This suggests that additional control and optimization of these components contribute to better energy management and efficiency. Hence, integrating advanced components such as microcontrollers and circuit modules can significantly improve the trainer's functionality and efficiency in its performance in terms of battery consumption.

Construction Time Frame

Table VIII presents the working activities such as designing, constructing, pre-testing and revising, final testing, and the total number of hours allotted to making the trainer.

Table VIII Work Activities and Time Allotment

Working Activities	Time Allotment
Designing	7 days
Constructing	
• Case	10 days
• Current Booster and Capacitor bank circuit module Assembling	3 days
• Final Product Assembly	6 days
Pre-testing and Revising	3 days
Final Testing for Battery Operation	3 days
Overall construction timeframe	**32 days**

Evaluation Procedure

The Photovoltaic System Trainer was completed through pre-testing, revising, and final testing, which was done in consultation with the experts using the researcher-made survey questionnaires for product quality dimensions and acceptability. The survey questionnaires were validated using a content validation tool and underwent reliability testing. The study was conducted, and the data was analyzed and interpreted using statistical tools.

Instrumentation

This section includes the research instruments and their validity and reliability.

Research Instruments

A questionnaire is a set of systematically and orderly arranged questions prepared to generate data or information to answer the main problem and sub-problems or to confirm or reject the hypothesis [10]. [9], questionnaires provide a sense of anonymity to respondents, encouraging more honest and unbiased responses. This highlights their advantage in gathering candid opinions and feedback.

In this study, the researcher made two (2) research instruments. The first is to evaluate the product quality dimensions regarding performance efficiency, durability, reliability, maintainability, and conformance. The quality dimensions were based on David Garvin's eight (8) Product Quality (1987) and ISO/IEC 25010 (2011) with the following interpretation guide:

Score Range	Mean Score Ranges		Verbal Interpretation
5	4.50-5.00	-	Very Good
4	3.50-4.49	-	Good
3	2.50-3.49	-	Moderate
2	1.50-2.49	-	Low
1	1.00-1.49	-	Very Low

The second research instrument is to determine the trainer's acceptability in terms of design, functional suitability, security, usability, and portability using the following interpretation guide:

Score Range	Mean Score Ranges		Verbal Interpretation
5	4.50-5.00	-	Very Highly Acceptable
4	3.50-4.49	-	Highly Acceptable

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3	2.50-3.49	- Moderately Acceptable
2	1.50-2.49	- Unacceptable
1	1.00-1.49	- Very Unacceptable

Validity of the Research Instrument

The validity of the research instruments was rigorously established through a combination of content analysis and expert reviews. The validity of the researcher-made instrument was evaluated using the criteria set forth by Lawshe (1975). Lawshe's method has been widely used to establish and quantify content validity in diverse fields [2]. This method engages a panel of experts who assess items and assign them to one of three categories: "essential," "useful, but not essential," or "not necessary." Items identified as "essential" by many panel experts are subsequently incorporated into the final instrument, while those items failing to achieve this critical level are rejected.

In this study, the research instrument used to evaluate the quality dimensions of the trainer was validated by nine (9) experts. In contrast, the acceptability of the trainer was validated by eight (8) experts in educational technology.

Applying the formula in calculating the Content Validity Ratio (CVR) by Lawshe, with nine (9) experts to rate, six items were rejected on the quality dimensions, and the remaining 45 items with values of 0.78 to 1.00 were retained. Similarly, for the acceptability of the trainer, Lawshe's formula with eight (8) experts resulted in the rejection of 1 item, while the remaining 43 items were retained with values ranging from 0.75 to 1.00.

The recommendations and suggestions provided by the validators for improving the research instruments were thoughtfully considered after the validation process.

Reliability of the Research Instrument

Reliability of a research instrument is a crucial aspect that reflects the consistency and stability of measurement over repeated trials to ensure dependable and replicable results. [18] emphasize that the reliability of research instruments, as noted in their study, directly influences the trustworthiness of data collected, enabling researchers to draw accurate conclusions and make valid inferences.

In this study, reliability testing was conducted using the Cronbach alpha (α) test to measure the reliability or internal consistency of the instrument [20].

The instrument intended to evaluate the quality dimensions of the photovoltaic system trainer underwent a dry run among four (4) Electrical and five (5) Electronics Trainers of the Regional Training Center (RTC) of TESDA – Talisay City. On the other hand, the instrument intended to evaluate the acceptability of the photovoltaic system trainer was subjected to a dry run among thirty (30) Electronic Product Assembly Servicing (EPAS)/ Electrical Installation Maintenance Servicing (EIM) NC II trainees.

These individuals were not the actual respondents of the study.

The reliability result was excellent for quality dimensions, yielding a result of 0.952, and similarly for acceptability, with a result of 0.950, indicating that the instruments are reliable.

Data to be Gathered

The following data were gathered to determine the trainer's extended battery operation, quality dimensions, and acceptability.

The extend battery operation was evaluated and tested to assess its capabilities using three (3) configurations. Mean scores and standard deviations were used to evaluate product quality and acceptability.

There were 75 respondents for the quality dimensions, which includes the following experts: EIM/EPAS TESDA Assessors (10), Electrical Supervisors (15), Electronic/Electrical Engineers (20), EIM Teachers/Trainers (10), EPAS Teachers/Trainers (10), and Electronic/Electrical technicians (10).

Moreover, for the acceptability of the trainer, there were 300 respondents, which included the following: BSIT Electrical Technology Students (60), BSIT Electronics Technology Students (60), BTLED Industrial Arts Students (60), BS in Electronics Engineering (40), and Senior High School TVL Track major in Electronics (40) and Electrical (40).

Parameters for Analysis

Appropriate tools relevant to the study will be used to answer the research objectives. For Objective number two (2), the evaluation of the trainer's quality dimensions in terms of performance efficiency, durability, reliability, maintainability, conformance, and mean and standard deviation will be used.

Mean scores were interpreted as follows:

Score Range	Mean Scores Range	Verbal Interpretation

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5	4.50-5.00	- Very Good
4	3.50-4.49	- Good
3	2.50-3.49	- Moderate
2	1.50-2.49	- Low
1	1.00-1.49	- Very Low

For objective number three (3), the evaluation of the acceptability of the trainer in terms of design, functional suitability, security, usability, portability, and mean and standard deviation were used.

Mean scores were interpreted as follows:

Score Range	Mean Scores Range	Verbal Interpretation
5	4.50-5.00	- Very Highly Acceptable
4	3.50-4.49	- Highly Acceptable
3	2.50-3.49	- Moderately Acceptable
2	1.50-2.49	- Unacceptable
1	1.00-1.49	- Very Unacceptable

Cost Analysis

Table IX shows the costs incurred in the production of the trainer device. The total cost of materials was Php 21,290.00, miscellaneous expenses Php 2,000.00, and labor cost Php 6,387.00. The researcher approached three electronic shops offering audio processor tour case assembly services to inquire about the labor cost in the project's fabrication, amounting to 30% of the total cost of materials based on the Labor-Material Percentage Method cited by [3]. Overall, the cost of the Photovoltaic System Trainer is Php 29,677.00.

Table IX Cost of Trainer

Description	Cost
Bill of Materials	Php 21,290.00
Miscellaneous	Php 2,000.00
Labor Cost (30%)	Php 6,387.00
Overall Costs	**Php 29,677.00**

Ethical Consideration

The researcher adhered to ethical guidelines throughout the study, beginning by asking permission from appropriate authorities. Before the respondents engaged in the study, the researcher provided them with a consent form outlining the voluntary nature of participation with details about the nature and purpose of the study.

To ensure confidentiality, the researcher kept confidential and anonymized all personal information obtained during the study in reports to prevent potential harm or breaches of trust. After the research and presentation are completed, the collected data will be shredded and discarded. Additionally, any personal data files will be deleted to prevent information reconstruction. In line with transparency and knowledge dissemination principles, the researcher plans to share the study's outcomes by presenting them at national and international research forums, followed by publication in reputable journals.

Additionally, hardbound copies of the research will be deposited in the CIT office and library as a reference and scholarly inquiry.

III. Results and Discussion

I. Technical Features

The study's first objective was to design and construct a Photovoltaic System Trainer with the following technical features: dual-powered device, interactive learning, and extended battery operation.

Dual-powered device

The trainer was designed with a dual-powered device. It uses two power sources for charging: solar power and AC power. Solar panels harness sunlight, converting it into electricity to charge the main battery and capacitor bank. An AC power source of 220V connects to a battery charger with an integrated automatic charger/discharger circuit for safe and effective charging. This setup provides a significant advantage during hands-on activities, preventing power failures and interruptions during training sessions.

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Interactive learning

The trainer has an interactive learning feature. This feature can be easily configured depending on the demands of the learning activity. Students can explore how solar energy works in real life by blending theoretical concepts with practical applications. Students actively explore the photovoltaic system through interactive activities, demonstrations, and experiments. They can also adjust settings and see immediate results, which helps them understand how photovoltaic systems work. 61

Extend battery operation

The last design feature of the trainer is extending battery operation. Integrating a microcontroller and a circuit module assembly ensures the extension of battery operations. These configurations of circuit modules work well to keep the battery working effectively for a longer time when using the trainer. This setup is good at keeping the battery running smoothly during long periods of use. These circuit modules optimize energy management, enabling the trainer to operate efficiently for extended periods without compromise.

Product Quality Evaluation

The study's second objective was to evaluate the product quality in terms of performance efficiency, durability, reliability, maintainability, and conformance, shown and discussed in Tables 10 to 14, respectively. Table 15 discusses the overall evaluation of product quality.

Table X Result of the Evaluation of Product Quality in terms of Performance Efficiency

Performance efficiency	Mean	SD	Interpretation
The trainer…			
1. can operate both in a solar and/or AC power sources.	5	0.00	Very Good
2. can continuously store 12V DC in its capacitor bank and battery, if solar and/or AC power sources was used.	4.84	0.37	Very Good
3. can monitor output power, voltage, and current in solar energy simulation.	4.80	0.41	Very Good
4. can supply power to DC operated device like LED lights, cooling fan, Bluetooth speaker, DC electronic circuit projects.	4.84	0.37	Very Good
5. can be used as charger for external batteries.	4.84	0.37	Very Good
6. can monitor the AC loads being used, ensuring that the amount of electricity being used is within the system's limits.	4.84	0.37	Very Good
7. is effective during solar energy conversion processes.	4.80	0.41	Very Good
8. facilitates easy navigation and adaption to various learning environments.	4.68	0.48	Very Good
9. can consistently perform both theoretical and practical operation.	4.92	0.28	Very Good
10. can be repeatedly used without compromising its normal operations standard.	4.88	0.23	Very Good
11. can perform several configurations when conducting an actual experimentation.	4.92	0.28	Very Good
As a whole	**4.85**	**0.11**	Very Good

The evaluation of the Photovoltaic System Trainer's performance efficiency highlighted several key areas, with some criteria receiving notably high scores and others relatively lower scores.

The trainer excels in several areas, achieving very high scores. Its ability to operate using both solar and AC power sources received a perfect mean score of 5.00 with no deviation, indicating unanimous agreement on its excellent performance. Additionally, the trainer's consistent performance in both theoretical and practical operations was rated highly, achieving a mean score of 4.92 with a standard deviation of 0.28. This reflects its effectiveness in delivering clear and comprehensive instruction, ensuring that trainees not only understand theoretical concepts but are also well-prepared for practical applications. Such high ratings underscore the trainer's ability to foster skill development, enhance learning outcomes, and maintain a professional standard throughout the training process. The ability to perform several configurations during actual experimentation was also highly rated, with a mean score of 4.92 and an SD of 0.28.

On the other hand, some criteria received relatively lower scores, although they were still rated as very good. The trainer's ability to facilitate easy navigation and adapt to various learning environments received a mean score of 4.68 and a standard deviation of 0.48, indicating slightly more variability in responses. The capability to supply power to DC-operated devices like LED lights, cooling fans, Bluetooth speakers, and DC electronic circuit projects was rated very good, with a mean of 4.84 and SD of 0.37. Similarly, the trainer's capacity to continuously store 12V DC in its capacitor bank and battery, its ability to monitor AC loads, and its consistent performance without compromising its normal operations standard were all rated very good, each with a mean score of 4.84 and SD of 0.37.

AS a whole, the Photovoltaic System Trainer received an impressive overall mean score of 4.87 with a low standard deviation of 0.11, indicating a consistently high level of performance efficiency. Each criterion received a rating of "Very Good," demonstrating the trainer's effectiveness and reliability across various performance metrics. The highest scores highlight the trainer's strengths, particularly in operating with dual power sources and consistently performing theoretical and practical

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operations. The relatively lower scores, while still strong, suggest areas for potential improvement, such as facilitating easier navigation and supplying power to various DC-operated devices. These insights provide a comprehensive understanding of the trainer's performance and areas for refinement.

Table XI Result of the Evaluation of Product Quality in terms of Durability

Durability	Mean	SD	Interpretation
The trainer…			
1. is sturdy enough even when mishandled.	4.80	0.41	Very Good
2. is made of materials that can exist for a long period of time without quality deterioration.	4.92	0.28	Very Good
3. can withstand high temperature and humidity.	4.64	0.49	Very Good
4. employs high quality materials to effectively withstand of continuous operation and minimizing wear and tear.	4.92	0.28	Very Good
5. uses wiring that complies with industry standards.	4.88	0.33	Very Good
6. has a tourcase made of quality type plywood with scratch-resistant formica.	4.88	0.33	Very Good
7. can ensure long-term usage without adverse effects on its performance.	4.92	0.28	Very Good
8. has an installed aluminum case corner brackets to provide reinforced protection to extend its lifespan.	5.00	0.00	Very Good
As a whole	**4.86**	**0.25**	**Very Good**

In Table XI, the Photovoltaic System Trainer's durability revealed several key strengths and areas with slightly lower scores, though all criteria were rated very good.

The trainer excelled in several aspects of durability. It is designed features aluminum case corner brackets that provide reinforced protection. and it also receives a high score of 5.00 with no deviation (SD = 0.00). This indicates unanimous agreement on its exceptional durability.

The materials used for the trainer are built to last without deteriorating in quality over time and for long-term usage without adverse effects on performance, earning a high mean score of 4.92 with a standard deviation of 0.28

The trainer uses industry-standard wiring and has a tour case made from quality plywood with scratch-resistant Formica. Both rated very good, with mean scores of 4.88 and SD of 0.33. It employs high-quality materials that effectively withstand continuous operation and minimize wear and tear, achieving a mean score of 4.88 and an SD of 0.33.

While all scores were high, some areas showed slightly more variability. The trainer’s sturdiness when mishandled was rated very good, with a mean score of 4.80 and a standard deviation of 0.41. Its ability to withstand high temperatures and humidity was also rated very good, with a mean score of 4.64 and an SD of 0.49.

Overall, the Photovoltaic System Trainer received an impressive mean score of 4.86 with a low standard deviation of 0.25, demonstrating consistently high durability. All criteria were rated "Very Good," showcasing the trainer's robustness and reliability. The highest scores, with mean scores of 5.00 and SD of 0.00, emphasized its designed features aluminum case corner brackets that provide reinforced protection. Areas with slightly lower scores, while still strong, suggest opportunities for improvement in enhancing the trainer's ability to withstand high temperatures and humidity. This thorough evaluation provides a clear picture of the trainer's durability and highlights both its strengths and areas for further enhancement.

The finding is supported by the study of [21] entitled “Onymous Early-life Performance Degradation Analysis of Recent Photovoltaic Module Technologies.” They found out that the recent PV module technologies show potential for lifetimes beyond 30 years, with some showing degradation rates that exceed warranty limits, while others show potential for lifetimes beyond 30 years due to the module size, use of new materials like anti-reflection and anti-soiling coatings, thinner glass, new encapsulants, and back sheets, or other concepts such as split cells, dense interconnection designs (shingling), or increased number and topology of busbars or wires.

Table XII Result of the Evaluation of Product Quality in terms of Reliability

Reliability	Mean	SD	Interpretation
The trainer…			
1. can continuously operate even in the absence of AC power line source.	5	0	Very Good
2. can maintain its standard performance during everyday use.	4.80	0.41	Very Good
3. can continuously operate within 3 hours training session.	4..88	0.33	Very Good
4. can be trusted when learning about solar energy and its application.	5	0	Very Good
5. can consistently maintained its electrical power through its solar panel.	4.96	0.2	Very Good
6. can regulate the flow of electricity from the solar panel to battery storage.	4.96	0.2	Very Good
7. can invert DC power from the battery storage into AC power for external AC loads.	5	0	Very Good
8. can consistently generate and store electrical energy from the sun, providing a dependable renewable energy source.	4.96	0.2	Very Good
As a whole	**4.95**	**0.01**	**Very Good**

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Table XII shows the result of the product quality evaluation in terms of reliability. The average mean score was 4.95, interpreted as Very Good, with a standard deviation of 0.01.

The table further revealed that the highest obtained mean score was 5.00 on the items “can continuously operate even in the absence of an AC power line source,” “can be trusted when learning about solar energy and its application,” and “can invert DC power from the battery storage into AC power for external AC loads,” all interpreted as Very Good. Conversely, the lowest mean score was 4.80 on the item “can maintain its standard performance during everyday use,” which is still interpreted as Very Good.

These findings indicate that the reliability of the trainer is Very Good, implying stable functions during continuous operations. This suggests that the trainer exhibits exceptional reliability.

According to [16], reliability refers to the extent to which a system, product, or component executes designated functions within predetermined conditions over a specified time frame. In line with this, the trainer demonstrated faultlessness, evident in its ability to operate continuously, even without an AC power line source. The trainer is highly operational and accessible when required for use, maintaining its standard performance during everyday use and within training sessions. This availability ensures the trainer is always ready to perform as expected, without downtime.

Furthermore, the trainer consistently maintains electrical power through its solar panel and regulates the flow of electricity from the solar panel to battery storage, showcasing its fault tolerance. This capability allows the trainer to handle unexpected disruptions and continue functioning smoothly. Additionally, the trainer demonstrates recoverability by consistently generating and storing electrical energy from the sun, enabling it to recover and re-establish the system's desired state in the event of interruptions or failures.

These characteristics collectively contribute to the trainer's effectiveness as an educational tool for learning about photovoltaic systems. The trainer’s high mean scores in various aspects underscore its reliability. The ability to continuously operate without an AC power line source ensures that learning sessions are not interrupted by power outages, providing a seamless educational experience. Trustworthiness in learning about solar energy and its applications signifies that the trainer is a credible resource, enhancing the quality of education and ensuring that learners gain accurate and practical knowledge.

The capability to invert DC power from battery storage into AC power for external AC loads highlights the trainer’s versatility and practical application in real-world scenarios. This feature allows students to understand the conversion process of solar energy, bridging theoretical knowledge with practical application. The consistently high performance during everyday use further reinforces its reliability, ensuring it meets educational needs without frequent maintenance or disruptions.

The trainer's alignment with ISO 25010 standards in terms of faultlessness, availability, fault tolerance, and recoverability ensures it remains a robust and dependable tool for photovoltaic education. These qualities enhance the learning experience and instill confidence in both educators and students regarding the trainer's capabilities.

In summary, the trainer's exceptional reliability, as demonstrated by its high mean scores of 5.00 and 4.80 and its adherence to ISO 25010 standards, makes it an invaluable asset for teaching and learning about solar energy systems. Its ability to maintain performance under various conditions and its practical features contribute to its effectiveness as a comprehensive educational tool.

Table XIII Result of the Evaluation of Product Quality in terms of Maintainability

Maintainability	Mean	SD	Interpretation
The trainer…			
1. uses materials that are locally available in the market.	4.80	0.41	Very Good
2. can be repaired by any related technical expert.	4.64	0.64	Very Good
3. uses tools and equipment which are readily accessible.	5	0.00	Very Good
4. is easy to repair.	4.80	0.41	Very Good
5. has a simple circuit designed for easy maintenance even without specialize training.	4.76	0.52	Very Good
6. is easy to keep safely when assembling or disassembling.	4.80	0.41	Very Good
7. has a maintenance procedure which are time and cost-effective.	4.88	0.44	Very Good
8. can set automatically the self-charged operation if the battery is in low voltage and automatically shut-off when the battery is full.	4.80	0.50	Very Good
As a whole	**4.81**	**0.20**	**Very Good**

Table XIII shows the result of the evaluation of product quality in terms of maintainability. The findings indicate that the maintainability of the trainer was Very Good, with means ranging from 4.64 to 5.00. The highest obtained mean score was on the item “uses tools and equipment which are readily accessible,” interpreted as Very Good, while the lowest mean score was on the item “can be repaired by any related technical expert,” still interpreted as Very Good. There is homogeneity of the responses, as shown in the standard deviation ranging from 0.00 to 0.64.

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ISO 25010 states that maintainability is the degree of efficacy and efficiency with which a system or product may be adjusted to enhance, rectify, or adapt to changes in the requirements and environment. The photovoltaic system trainer adheres to ISO 25010 standards by using locally available materials, ensuring that replacements and repairs can be done quickly and at a low cost. The simple design of the trainer makes it easy to understand and work with, reducing the complexity involved in maintenance tasks.

Easy repair procedures further contribute to the trainer's maintainability. These procedures allow any related technical expert to perform necessary repairs efficiently, ensuring minimal downtime and maintaining the trainer's functionality. Additionally, the automatic operation features of the trainer enhance its maintainability by reducing the need for constant manual intervention, which in turn minimizes the potential for human error and wear over time.

These characteristics ensure that the trainer can be modified, repaired, and adapted to changes in requirements or environmental conditions with minimal effort and without compromising its functionality or quality. The consistently very high ratings reflect its adherence to maintainability standards, making it an effective and efficient tool for photovoltaic education. The ease of access to tools and equipment, straightforward repair procedures, and adaptive design all contribute to the trainer's overall effectiveness and efficiency in maintenance.

To sum up, the trainer's high mean scores ranging from 4.64 to 5.00 and alignment with ISO 25010 standards highlight its exceptional maintainability. Using locally available materials, simple design, easy repair procedures, and automatic operation features ensure that the trainer remains a reliable and efficient educational tool, capable of adapting to changes and maintaining its quality over time.

Table XIV Result of the Evaluation of Product Quality in terms of Conformance

Conformance	Mean	SD	Interpretation
The trainer…			
1. can work according to its standard operating procedure and specifications.	4.92	0.28	Very Good
2. can provide accurate and precise measurements of solar energy generation.	4.96	0.20	Very Good
3. possesses the required Electrical and Electronics training competencies.	4.96	0.20	Very Good
4. covers a wide range of topics and concepts about photovoltaic technology.	5	0	Very Good
5. can provide a variety of teaching and learning approaches.	5	0	Very Good
6. has a safety standard for sustainable operations.	4.96	0.20	Very Good
7. ensures alignment with educational and industry requirements.	4.92	0.28	Very Good
8. incorporates standard materials and components in its design.	4.76	0.52	Very Good
9. can be used as a simulator for teaching basic photovoltaic operation.	4.88	0.44	Very Good
10. can be used as an AC/DC external power input sources if power failure is encountered.	5	0	Very Good
As a whole	**4.94**	**0.11**	**Very Good**

Table XIV presents an evaluation of product quality in terms of conformance, showing an average mean score of 4.94 with a standard deviation of 0.11, both interpreted as Very Good. Notably, the highest mean score of 5.00 was obtained for items such as its ability to covering a wide range of topics and concepts about photovoltaic technology, providing a variety of teaching and learning approaches, and is used as an AC/DC external power input source if a power failure is encountered. Conversely, the lowest mean score was 4.76 for the item "incorporates standard materials and components in its design," which is still interpreted as Very Good. These results suggest that the trainer demonstrates excellent conformance, indicating it is well-suited for BSIT Electronics and Electricity technology and BTLED Industrial Arts courses. This alignment with the course curriculum implies that the trainer effectively meets the learning competencies outlined in the curriculum.

Supporting this, [11] developed a solar trainer for educational use in studying photovoltaic systems within a laboratory setting. Their trainer allows for investigating various balances of system components and studying environmental impacts on power generation using solar photovoltaic panels.

Table XV Overall Quality Evaluation of the Photovoltaic System Trainer

Items	Mean	SD	Interpretation
1. Performance efficiency	4.85	0.11	Very Good
2. Durability	4.86	0.25	Very Good
3. Reliability	4.95	0.10	Very Good
4. Maintainability	4.81	0.20	Very Good
5. Conformance	4.94	0.11	Very Good
As a whole	**4.88**	**0.20**	**Very Good**

Table XV comprehensively assesses the photovoltaic system trainer's overall quality, evaluated across several key dimensions: performance efficiency, durability, reliability, maintainability, and conformance.

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For performance efficiency, the trainer received a mean score of 4.85 with a standard deviation of 0.11, interpreted as Very Good. This indicates that the trainer operates effectively and meets the expected performance standards. Similarly, the durability of the trainer was also rated with a mean score of 4.86 and a standard deviation of 0.25, suggesting that the trainer is robust and capable of withstanding wear and tear, ensuring a long service life.

Regarding reliability, the trainer achieved a slightly higher mean score of 4.95 with a standard deviation of 0.10, also interpreted as Very Good. This high-reliability score indicates that the trainer consistently performs well and is dependable under various conditions. The maintainability of the trainer, while receiving the lowest mean score of 4.81, still falls within the Very Good range, with a standard deviation of 0.20. This suggests that the trainer is relatively easy to maintain and repair, though there may be slight room for improvement in this area.

Conformance received the highest mean score of 4.94 with a standard deviation of 0.11, indicating that the trainer adheres closely to the specified standards and requirements, ensuring it meets the designed criteria and user expectations.

The overall mean score for the quality evaluation of the photovoltaic system trainer is 4.88, with a standard deviation of 0.20, interpreted as Very Good. This reflects the high quality of the trainer across all evaluated dimensions, and the low standard deviation suggests consistency in the quality ratings, indicating that users generally agree on the trainer's superior performance and reliability. In could be gleaned from the results that the photovoltaic system trainer excels in performance efficiency, durability, reliability, maintainability, and conformance. These findings suggest that the trainer is a well-rounded, high-quality educational tool that effectively meets the needs of its users and aligns with the standards required for teaching photovoltaic technology.

Acceptability Evaluation

The third objective of the study was to determine the acceptability of the trainer in terms of design, functional suitability, security, usability, and portability, which are shown and discussed in Tables XVI to XX, respectively. Table XXI discusses the overall result of the evaluation of the acceptability of the trainer.

Table XVI Result of the Evaluation of Acceptability of the Photovoltaic System Trainer in terms of Design

Design	Mean	SD	Interpretation
The trainer…			
1. is portable and easy to carry.	4.83	0.45	Very Highly Acceptable
2. can operate both in a solar and/or AC power sources.	4.95	0.27	Very Highly Acceptable
3. has well-arranged parts according to its functions.	4.96	0.20	Very Highly Acceptable
4. is transparent and the parts are easily identified.	4.93	0.33	Very Highly Acceptable
5. has a digital display that is bright and clear enough for effective usage	4.98	0.15	Very Highly Acceptable
6. has an interface design which can easily monitor output power, voltage, and current during solar energy simulation.	4.99	0.09	Very Highly Acceptable
7. has an interface design which can easily monitor a unit price of an electrical consumption.	4.95	0.22	Very Highly Acceptable
8. has a size and weight which is appropriate for classroom use.	4.95	0.22	Very Highly Acceptable
9. has connectors and ports that are strategically positioned and arranged properly.	4.97	0.17	Very Highly Acceptable
10. is clearly labeled for easy use.	4.93	0.27	Very Highly Acceptable
As a whole	**4.94**	**0.12**	**Very Highly Acceptable**

As for the design, Table XVI shows the results of evaluating the acceptability of the Photovoltaic System Trainer. The findings indicate that the trainer's design was deemed Very Highly Acceptable, with mean scores ranging from 4.83 to 4.99. The highest mean score was attributed to the item "has an interface design which can easily monitor output power, voltage, and current during solar energy simulation," interpreted as Very Highly Acceptable. Conversely, the lowest mean score was for the item "is portable and easy to carry," still interpreted as Very Highly Acceptable.

The homogeneity of responses is evidenced by the standard deviation values ranging from 0.09 to 0.45. This suggests a strong consensus among respondents regarding the design's quality. The high mean scores, particularly for the interface design, imply that the trainer provides an exceptionally well-designed platform for monitoring output power, voltage, and current during solar energy simulation. This intuitive and effective interface allows users to monitor and understand the performance of the photovoltaic system efficiently.

Comprehensive monitoring and analysis of photovoltaic systems play a vital role. In their work, they reported the integration of monitoring, modeling, and simulation of PV systems within the same environment, which can provide real-time information on system behavior. This solution enables the acquisition and control of all necessary data from the PV system, evaluation of the main model parameters of PV modules and arrays, calculation of the performance ratio (PR) and yields of the system, creation of hypertext markup language (HTML) and Excel Spreadsheet (XLS) report files, and visualization of all these data and the dynamic system behavior in real-time.

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Table XVII Result of the Evaluation of Acceptability of the Photovoltaic System Trainer in terms of Functional Suitability

Functional suitability	Mean	SD	Interpretation
The trainer…			
1. can continuously operate properly even in the absence of AC power line source.	4.93	0.31	Very Highly Acceptable
2. can continuously store 12V DC in its capacitor bank and battery, if solar and/or AC power sources were used.	4.98	0.15	Very Highly Acceptable
3. can supply DC operated device like LED lights, cooling fan, Bluetooth speaker, DC electronic circuit projects	4.96	0.19	Very Highly Acceptable
4. has battery voltage output that can be monitored during charging and discharging battery operations.	4.97	0.22	Very Highly Acceptable
5. provides an actual input-output data in terms of power, voltage, and current.	5.00	0.00	Very Highly Acceptable
6. can monitor voltage, current and power outputs during actual operation.	4.98	0.18	Very Highly Acceptable
7. can be used as an AC/DC external power input sources if power failure is encountered.	4.94	0.24	Very Highly Acceptable
8. provides self-charging if the battery is low power voltage.	4.96	0.23	Very Highly Acceptable
9. can be used for several experimentation set up/ways.	4.95	0.22	Very Highly Acceptable
10. is stable during its everyday use.	4.94	0.26	Very Highly Acceptable
11. can operate in indoor and outdoor applications.	4.97	0.17	Very Highly Acceptable
12. can operate within 3 hours training session using internal battery.	4.98	0.13	Very Highly Acceptable
As a whole	**4.96**	**0.10**	**Very Highly Acceptable**

Regarding functional suitability, Table XVII shows that the average mean score was 4.96, interpreted as Very Highly Acceptable, with a standard deviation of 0.10. The data analysis further revealed that the highest obtained mean score was 5.00, interpreted as Very Highly Acceptable, for the item "provides actual input-output data in terms of power, voltage, and current." This underscores the trainer's strong emphasis on accurate data monitoring and measurement capabilities, which respondents highly value for its ability to provide precise and detailed data.

Conversely, the lowest obtained mean score was 4.93 for the item "can continuously operate properly even in the absence of an AC power line source," which is still interpreted as Very Highly Acceptable. This indicates that the trainer meets or exceeds industry standards, ensuring quality education and skills development. The trainer's very high level of acceptability suggests its suitability for integration into educational programs such as BSIT Electronics and Electricity Technology and BTLED Industrial Arts courses. Educators can leverage the trainer's functionality to enhance hands-on learning experiences and reinforce theoretical concepts related to solar energy principles and photovoltaic system operation.

Moreover, the trainer adheres to the ISO 25010 standard for functional suitability. Its functional completeness addresses various tasks and objectives, from continuous operation in the absence of AC power to supplying power to DC-operated devices and providing real-time monitoring of voltage, current, and power outputs, thus fulfilling a wide range of requirements. Its functional correctness ensures accurate results, while its functional appropriateness is evidenced by its ability to serve as an external power source during power failures, self-charge when the battery is low, and operate within defined training sessions using primary battery power. These features enhance its usability and suitability for diverse learning scenarios.

Table XVIII Result of the Evaluation of Acceptability of the Photovoltaic System Trainer in terms of Security

Security	Mean	SD	Interpretation
The trainer…			
1. has secured briefcase lock to prevent unauthorized person to open.	4.94	0.23	Very Highly Acceptable
2. has key system which prevent unauthorized person to operate.	4.94	0.23	Very Highly Acceptable
3. has a key control system for the overall security measures.	4.98	0.15	Very Highly Acceptable
4. has an optocoupler relay switch which can prevent damage when misconnected or mis wired.	4.95	0.23	Very Highly Acceptable
5. has a tamper-resistant tourcase to prevent unauthorized person to access inside components.	4.95	0.22	Very Highly Acceptable
6. can automatically activate the cooling fan to prevent it from overheating.	4.96	0.25	Very Highly Acceptable
7. has a safety feature to safeguard both users and the device during operation.	4.85	0.49	Very Highly Acceptable
As a whole	**4.94**	**0.18**	**Very Highly Acceptable**

In terms of security, Table XVIII shows that the average mean score was 4.94, interpreted as Very Highly Acceptable, with a standard deviation of 0.18. The highest-rated security feature, with a mean score of 4.98, was "has a key control system for the overall security measures," interpreted as Very Highly Acceptable. The lowest-rated security feature, with a mean score of 4.85, was "has a safety feature to safeguard both users and the device during operation," still interpreted as Very Highly Acceptable.

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The homogeneity of the responses is evidenced by the standard deviation values, which range from 0.15 to 0.49. This indicates a strong consensus among respondents regarding the importance and effectiveness of the security features. These findings imply that respondents place significant emphasis on security when evaluating the trainer, reflecting a broader trend in technology adoption.

This focus on security aligns with the research of [17], which highlights that security concerns are paramount in adopting and using technological devices. The device manufacturer can enhance user trust and confidence in the product by prioritizing security features such as secured locks, key control systems, and technical safeguards. This emphasis on robust security measures ensures that the trainer meets educational needs and addresses critical safety and security concerns, further supporting its integration into educational programs.

Table XIX Result of the Evaluation of Acceptability of the Photovoltaic System Trainer in terms of Usability

Usability	Mean	SD	Interpretation
The trainer…			
1. is useful when conducting experiments about solar powered electrical wiring connection.	4.93	0.31	Very Highly Acceptable
2. has controls and features which are easy to understand and operate.	4.96	0.26	Very Highly Acceptable
3. can be adapted to various training needs.	4.95	0.27	Very Highly Acceptable
4. can adapt several configurations when connecting external input sources like solar panel, battery and others.	4.96	0.21	Very Highly Acceptable
5. suitable for utilization across various educational or training environments.	4.96	0.20	Very Highly Acceptable
6. is easy to operate when assembling and disassembling of the photovoltaic system.	4.96	0.20	Very Highly Acceptable
7. is useful for Electrical and Electronics trainees' skills development.	4.94	0.25	Very Highly Acceptable
8. is relevant and beneficial for learning solar power electrical wiring connection	4.97	0.17	Very Highly Acceptable
As a whole	**4.95**	**0.12**	**Very Highly Acceptable**

The evaluation of the acceptability of the Photovoltaic System Trainer in terms of usability shows overwhelmingly positive results, as indicated by high mean scores and low standard deviations across all assessed items. The overall average mean score for usability is 4.95, interpreted as Very Highly Acceptable, with a standard deviation of 0.12. This suggests that respondents found the trainer highly usable and effective for educational and training purposes.

One of the key aspects evaluated was the trainer's usefulness when conducting experiments about solar-powered electrical wiring connections, which received a mean score of 4.93 and a standard deviation of 0.31, interpreted as Very Highly Acceptable. This indicates that the trainer is perceived as a valuable tool for hands-on learning and practical application in this specific area.

The trainer's controls and features were also highly rated, with a mean score of 4.96 and a standard deviation of 0.26, suggesting that users find the interface intuitive and easy to operate. This ease of use is critical for ensuring that both instructors and students can effectively utilize the trainer.

Adaptability to various training needs and configurations is another strength of the trainer. The item evaluating this aspect received a mean score of 4.96 with a standard deviation of 0.20. In contrast, the ability to adapt several configurations when connecting external input sources like solar panels and batteries scored 4.96 with a standard deviation of 0.21. These results imply that the trainer can be versatile and customized to meet diverse educational requirements.

The suitability of the trainer for various educational or training environments was also rated highly, with a mean score of 4.95 and a standard deviation of 0.27, further supporting its broad applicability and relevance across different contexts. Similarly, the ease of operation when assembling and disassembling the photovoltaic system was rated with a mean score of 4.96 and a standard deviation of 0.20, emphasizing the trainer's user-friendly design.

In terms of its usefulness for Electrical and Electronics trainees' skills development, the trainer received a mean score of 4.94 and a standard deviation of 0.25, highlighting its effectiveness as a training tool. Additionally, its relevance and benefits for learning solar power electrical wiring connection were rated with a perfect mean score of 4.97 and a standard deviation of 0.17, indicating unanimous agreement on its value in this area.

The high mean scores and low standard deviations indicate a strong consensus among respondents that the Photovoltaic System Trainer is very highly acceptable in terms of usability. The trainer's user-friendly design, versatility, and effectiveness in enhancing skills development make it a valuable asset for educational and training programs focused on solar energy and photovoltaic systems.

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Table XX Result of the Evaluation of Acceptability of the Photovoltaic System Trainer in terms of Portability

Portability	Mean	SD	Interpretation
The trainer…			
1. can easily be transferred from one place to another.	4.94	0.26	Very Highly Acceptable
2. has a tourcase handle for easy transportation.	4.97	0.20	Very Highly Acceptable
3. is hassle-free during transportation.	4.95	0.26	Very Highly Acceptable
4. can be quickly assembled and disassembled for swift relocation.	4.93	0.27	Very Highly Acceptable
5. has size and weight that are suitable for storage and transport.	4.96	0.19	Very Highly Acceptable
As a whole	**4.95**	**0.15**	**Very Highly Acceptable**

Similarly, the evaluation of the acceptability of the Photovoltaic System Trainer in terms of portability demonstrates highly positive results, as evidenced by high mean scores and relatively low standard deviations across all evaluated items. The overall average mean score for portability is 4.95, interpreted as Very Highly Acceptable, with a standard deviation of 0.15. This indicates that respondents find the trainer highly portable and easy to transport and store.

The trainer's ease of transfer from one place to another received a mean score of 4.94 and a standard deviation of 0.26, interpreted as Very Highly Acceptable. This suggests that users appreciate the trainer's mobility, which is crucial for its use in various educational settings.

The presence of a tourcase handle for easy transportation was rated with a mean score of 4.97 and a standard deviation of 0.20, indicating that this feature significantly enhances the trainer's portability. Users find this feature particularly beneficial for moving the trainer between different locations.

Regarding the hassle-free nature of transporting the trainer, the mean score was 4.95 with a standard deviation of 0.26, still interpreted as Very Highly Acceptable. Although this item received the lowest mean score in the category, it highlights a slight area for potential improvement in reducing transportation-related challenges.

The trainer's capability for quick assembly and disassembly for swift relocation was rated with a mean score of 4.93 and a standard deviation of 0.27. This indicates that users find the trainer easy to set up and take down, which facilitates its use in dynamic educational environments.

The trainer's size and weight suitability for storage and transport received a mean score of 4.96 and a standard deviation of 0.19, indicating that users find the trainer conveniently sized and weighted for easy handling.

The evaluation of the acceptability of the Photovoltaic System Trainer in terms of portability demonstrates highly positive results, with an overall average mean score of 4.95, interpreted as Very Highly Acceptable, and a standard deviation of 0.15. The trainer's design features, such as the tourcase handle and its manageable size and weight, contribute to its ease of transportation, assembly, and storage, making it highly portable and suitable for various educational settings. This strong agreement among respondents highlights the trainer's practical value for hands-on learning and training in photovoltaic systems. The high level of acceptability implies that the trainer meets or exceeds industry standards for portability, aligning with Dudeck & Grebski's (2013) emphasis on the importance of portability in environments where flexibility and mobility are crucial.

Table XXI Overall Evaluation of the Acceptability of Photovoltaic System Trainer

Items	Mean	SD	Interpretation
1. Design	4.94	0.12	Very Highly Acceptable
2. Functional suitability	4.96	0.10	Very Highly Acceptable
3. Security	4.94	0.18	Very Highly Acceptable
4. Usability	4.95	0.12	Very Highly Acceptable
5. Portability	4.95	0.15	Very Highly Acceptable
As a whole	**4.95**	**0.13**	**Very Highly Acceptable**

Table XXI presents the overall evaluation of the acceptability of the Photovoltaic System Trainer. The mean score across all features evaluated was 4.95, interpreted as Very Highly Acceptable, with a standard deviation of 0.13. Among the items, Functional suitability obtained the highest mean score of 4.96, while design and security obtained the lowest mean score of 4.94, both rated as Very Highly Acceptable.

The very high acceptability rating of the Photovoltaic System Trainer in terms of design, functional suitability, security, usability, and portability indicates its significant potential in enhancing the quality of education, specifically in skill development for trainees such as BSIT Electronics and Electricity Technology and BTLED Industrial Arts students.

This finding is supported by [4] in his developmental study entitled "Prototype Training Device in Electrical Installation and Maintenance: Equipping Electrical Technology Students for National Competency Assessment," which found that the device was

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evaluated as very highly acceptable in terms of its ergonomic design, usability, efficiency, and portability, highlighting a strong correlation with the present study.

User Manual and Activity Sheets

The fourth objective of the study was to formulate a user manual and activity sheet. These materials were developed to guide users in utilizing the trainer effectively. Providing these materials in conjunction with the trainer allows students to set up the photovoltaic system while completing the required tasks.

The activity sheet was evaluated by eight experts using the CHMSU-CIMD Instrument for Evaluating Instructional Materials (BOT Resolution No. 55, s. 2010). The following are the number codes, mean score ranges, descriptions, and evaluation decision references.

Number Codes	Mean Score Ranges		Description
5	4.20-5.00	-	Excellent
4	3.40-4.19	-	Very Good
3	2.60-3.49	-	Good
2	1.80-2.59	-	Fair
1	1.00-1.79	-	Poor

Evaluation Decision Reference:

3.40-5.00	Compliant – Passed
1.00-3.39	Non-compliant - Failed

Table XXII Result of Activity Sheets' Evaluation

Criteria	Mean	SD	Interpretation	Decision Reference
Content Quality	4.90	0.21	Excellent	
Curricular Value	5.00	0.00	Excellent	
Appropriateness to User	4.83	0.27	Excellent	**PASSED**
Organization	4.90	0.21	Excellent	
Packaging	4.93	0.15	Excellent	
General Average	**4.91**	**0.17**	**Excellent**	

Table XXII presents the evaluation results of the activity sheets based on several criteria: content quality, curricular value, appropriateness to user, organization, and packaging. The overall average mean score is 4.91, interpreted as Excellent, with a standard deviation of 0.17. This indicates that the activity sheets are highly regarded across all evaluated aspects.

The content quality of the activity sheets received a mean score of 4.9 with a standard deviation of 0.21, interpreted as Excellent. This suggests that the content is comprehensive, well-structured, and effectively conveys the necessary information to the users. The relatively low standard deviation indicates consistent agreement among respondents regarding the high quality of the content.

Curricular value achieved a mean score of 5.00 with a standard deviation of 0.0, also interpreted as Excellent. This perfect score demonstrates unanimous agreement among respondents that the activity sheets are exceptionally valuable in aligning with and supporting the curriculum. Such high alignment is crucial for ensuring that educational materials are effective and relevant to the learning objectives.

The appropriateness to user criterion received a mean score of 4.83 with a standard deviation of 0.27, interpreted as Excellent, and a decision reference of PASSED. Although this category had the highest standard deviation among the criteria, indicating slightly more variation in responses, the mean score remains very high. This suggests that while the activity sheets are generally well-suited to the users, there may be minor areas for improvement to cater to diverse user needs more effectively.

The organization of the activity sheets was rated with a mean score of 4.9 and a standard deviation of 0.21, which was interpreted as excellent. This implies that the activity sheets are well-organized, allowing for ease of use and understanding. Consistency in the responses further highlights the reliability of this criterion.

Packaging received a mean score of 4.93 with a standard deviation of 0.15, interpreted as Excellent. The high score and low standard deviation indicate that respondents found the physical presentation and packaging of the activity sheets superior, enhancing their overall appeal and usability.

In conclusion, the activity sheets received an overall excellent rating across all evaluated criteria, with mean scores ranging from 4.83 to 5.0 and standard deviations indicating consistent positive feedback. These high ratings reflect the activity sheets'

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effectiveness, relevance, and quality, making them valuable educational tools for supporting the curriculum and enhancing user learning experiences.

User's Manual

The inclusion of a user manual with the Photovoltaic System Trainer is vital for fostering effective learning and skill development. Designed to provide comprehensive guidance, the manual covers essential aspects such as product specifications, features, parts and functions, operating procedures, maintenance, dos and don'ts, and troubleshooting. It equips users with clear instructions to confidently set up and operate the system while completing designated tasks. The activity sheets within the manual encourage independent learning, enabling students to acquire competencies at their own pace. By bridging theoretical knowledge with hands-on practice, the manual ensures a balanced understanding of the system's principles and operation.

Key sections of the manual further enhance its utility. The introduction outlines its purpose as a structured guide for hands-on activities, while the product specifications detail the trainer's dimensions, power requirements, and capabilities, ensuring safe and informed use. The product features highlight innovations like dual power sources, automatic battery management, and interactive learning configurations that support diverse training needs. The product parts and functions section explain each component's role, such as the solar panel for energy conversion and auxiliary ports for added functionality.

The operating procedures section provides step-by-step guidance for safe and efficient use, from setting up the solar panels to shutting down the system. Regular maintenance is emphasized to ensure the trainer's longevity, including cleaning, inspecting connections, and monitoring battery health. The dos and don'ts offer practical tips for proper use and precautions to prevent common issues. Finally, the troubleshooting guide helps users identify and resolve potential problems, ensuring minimal disruptions and continued operation. Together, these elements make the manual an indispensable resource for mastering the trainer and achieving a comprehensive learning experience.

IV. Summary of Findings

The following is the summary of the findings of the study:

1. The Photovoltaic System Trainer has three technical features: dual-powered device, interactive learning, and extended battery operation. These can reinforce students' comprehension, engagement, and practical skill development in photovoltaic system operations.
2. The quality of a Photovoltaic System Trainer in all dimensions, namely performance efficiency, durability, reliability, maintainability, and conformance, was very good.
3. The Photovoltaic System Trainer was highly acceptable in all technical features: design, functional suitability, security, usability, and portability.
4. The user manual and activity sheets were developed to guide users in utilizing the trainer effectively. The user manual was formulated to guide product specifications, features, parts and functions, operating procedures, maintenance, do's and don'ts, and troubleshooting guides. The activity sheets were designed for students conducting every experiment concerning photovoltaic system concepts. By incorporating these resources, teachers can facilitate and monitor learning competencies more easily.

V. Conclusions

The following conclusions are drawn:

I. The Photovoltaic System Trainer includes three essential technical features: dual-powered device, interactive learning, and extended battery operation. These features significantly enhance students' comprehension, engagement, and practical skill development in photovoltaic system operations. Incorporating dual-power capabilities ensures the trainer can function under various power conditions, providing reliability and flexibility. Interactive learning elements make the training more engaging and effective, fostering deeper understanding. Extended battery operation allows for uninterrupted training sessions, which is crucial for practical hands-on learning.

II. The quality of the Photovoltaic System Trainer in all dimensions—performance efficiency, durability, reliability, maintainability, and conformance—was rated as very good. High-quality standards across these dimensions suggest the trainer is a robust and reliable educational tool. This reliability ensures consistent performance over time, reducing the likelihood of disruptions in the learning process. The durability and maintainability of the trainer imply lower long-term costs and effort in upkeep, making it a cost-effective investment for educational institutions.

III. The Photovoltaic System Trainer was rated as very highly acceptable across all technical features, including design, functional suitability, security, usability, and portability. High acceptability indicates that the trainer meets user expectations and requirements effectively. Excellent design and usability enhance the learning experience by making the trainer easy to use and understand. Functional suitability ensures the trainer meets educational objectives, while security

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features provide a safe learning environment. Portability allows for flexibility in usage across different locations, facilitating broader application and accessibility.

IV. The user manual and activity sheets were developed to guide users in utilizing the trainer effectively. The user manual covers product specifications, features, parts and functions, operating procedures, maintenance, do's and don'ts, and troubleshooting guides. The activity sheets are designed for students to experiment with photovoltaic system concepts. These resources are crucial for maximizing the effectiveness of the trainer. The user manual provides comprehensive guidance, ensuring users can operate and maintain the trainer correctly, thus extending its lifespan and functionality. The activity sheets facilitate structured learning and experimentation, helping teachers to easily integrate the trainer into their curriculum and monitor student progress in mastering photovoltaic system concepts. This structured approach supports a more effective and organized learning environment.

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