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Research Article

Design and Development of a Compact LED-Based Double-Sided PCB Exposure Unit for Instructional Applications

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ABSTRACT

This paper was intended to design, develop, and test a single-sided and double-sided printed circuit board (PCB) double-sided exposure unit involving LED to be used in teaching electronics at electronics laboratories. To achieve its study, the research used a Research and Development (R&D) methodology with the ADDIE model that consists of analysis, design, development, implementation, and evaluation. The device was constructed during the development phase using local materials and an integrated control board comprising of regulated power supply, timer board, each panel of LED, and an alignment system to process a double-sided PCB. Performance testing was done to identify some of the operational parameters, which include DC voltage output, current output, PCB exposure time, development time and etching time. The first trial of optimization showed that with exposure time of 20 seconds, clear and well-defined patterns of the circuit were obtained without affecting quality. The acceptability was measured using a structured evaluation tool that was based on ISO/IEC 9126 standard of quality in electronic engineering to the members of electronics faculty, as well as, students at the Bulacan State University - Main and Bustos campuses. Evaluations made on the device are on the aspects of functionality, reliability, usability, maintainability, portability, operability, and safety. The findings revealed that there was an overall rating all criteria of high ratings that were marked as very acceptable with the computed grand mean of 4.78, representing high satisfaction and an instruction based appropriateness. The results verify the specially designed LED-based double-sided PCB exposure unit as a viable, effective and economical instructional resource to laboratory efficiency and assist in competency acquisition in PCB manufacturing.

***Keywords**: ADDIE model, developmental research, double-sided PCB, electronics education, instructional technology, ISO 9126 quality model, laboratory equipment evaluation, LED-based PCB exposure unit*

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Introduction

Due to the blistering development of the electronics technology, the world industry, economy, and life are still changing. Electronic platforms like smart phones, laptops, medical apparatus, automotive units, and industrial control units are such platforms that heavily depend on the use of printed circuit boards (PCBs) as their structural and electrical building blocks. PCBs mechanically support and electrically (with a conductor) interconnect the electronic components by conducting traces etched out of the copper sheets deposited on substrates that are non-conductive (Rao, 2022). Their invention transformed the manufacturing of electronics by substituting the massive point-to-point wiring with the small, dependable and inexpensive circuit integration.

Traditionally, the electronic assemblies were made by manual assembly methods whereby they used manually drawn or spotted wires assemblies but these were labor-intensive, subject to errors and could not be easily scalable to mass production. With the creation of PCB technology, many aspects like miniaturization, the increased reliability, and cost-effective production became possible, which also enabled innovation in consumer electronics, telecommunications, computing, and industrial automation to happen faster (Malvino and Bates, 2016). Current day PCB assembly methods such as multi-layers boards and surface mount technology form the basis of high density and high-performance in various industries.

The semiconductor and electronics industry are one of the most powerful players in the Philippine national economy. The Department of Trade and Industry (2023) indicates that electronics have a strong presence in total merchandise exports of the country and supports the importance of the sector in manufacturing, creation of jobs, and technological progress. The industry is still growing to more higher value-produced, research and development (R&D) and design innovation. This development highlights the growing constraint of technically skilled graduates that are not only equipped but also possess practical PCB design and fabrication skills.

Electronics engineering and technology education Students must be able to convert schematic diagrams to practical PCB layouts and develop prototype boards to gain practical laboratory and project learning. Even though the physical fabrication process especially exposure and etching may still be resources and time-consuming to do in instructional settings, the modern computer-aided design (CAD) software remains less difficult to do than schematic capture and layout design. Historical methods of PCB exposure can be very bulky in size and may only be able to expose a single side of the PCB and cannot be repeated, thus restricting the ability to be efficient and precise in the prototyping process.

PCBs have a positive photoresist which makes prototyping easier by allowing direct exposure of artwork directness to form high-resolution traces with fine line-width control. Nevertheless, traditional units of exposure in the practice of educational laboratories might not be of consistent light dispersion, energy efficiency, and bilateral alignment ability, which are highly necessary in fabricating trustworthy multilayer or double-sided boards (Williams, 2020). Lack of small and affordable exposure apparatus in the teaching laboratories can result to recidivism of fabrication fallacies, bigger material expenditure, and greater durations of time taken by students in project completion.

With these difficulties, it is necessary to design a better, small, and more energy-efficient PCB exposure system that would be used to instruct. The benefits of light-emitting diodes technology include low power consumption, long service life, homogenous light distribution, and low heat generation in comparison to the conventional UV fluorescent lamps (Singh & Kaur, 2021). By adding LED-based exposure and the ability to align orients on both sides, accuracy can be greatly improved, processing time can be slowed and learning outcomes achieved in PCB fabrication classes can be improved.

Using these teaching and technical requirements, this study recommends the design and manufacture of a small package LED-based, double-sided PCB exposure unit which will facilitate and speed up the PCB production process in institutionalized laboratories (Williams, T.,2020). Through its ability to offer a more effective, dependable, and student friendly exposure system, the study shall be targeting to improve physical learning experiences, minimized wastage of materials and help develop industry competencies ready electronics students.

Objective of the Study

The key aim of the study will be to design, develop and test a miniature LED-based two sided PCB exposure unit that could be used as a teaching aid by Electronics students in Bulacan State University.

In particular, the research questions of the study are the following:

1. The aim of the work is to develop an instructional PCB exposure unit that will allow the students to develop the patterns on the layouts of the printed circuit board onto pre-sensitized PCBs through LED based exposure technology.
2. To design the suggested LED-based PCB exposure unit (both sides) using the predetermined qualities of design.
3. To estimate the operations of the developed device with respect to:
   a. Maximum size of PCB to be printed,
   b. PCB exposure time,
   c. PCB development time, and
   d. PCB etching time.
4. 4. To evaluate the acceptability of the developed device according to the ISO/IEC 9126 quality characteristics and especially:
   a. Functionality
   b. Reliability
   c. Usability
   d. Maintainability
   e. Portability
   f. Operability
   g. Safety

Conceptual Framework

The paper is based on the Input-Process-Output (IPO) Model, which is the systems-based model to be frequently employed in technological and developmental studies to describe how the resources are converted into the functionalization of the input in form of the output using the systematic processes. In Figure 1, the IPO model gives a rational image of the systematic processes that manipulate the inputs to give concrete results (Hall and Fagen, 1956). It is commonly used in the development of instructional systems and engineering design research in order to give direction to product development and testing.

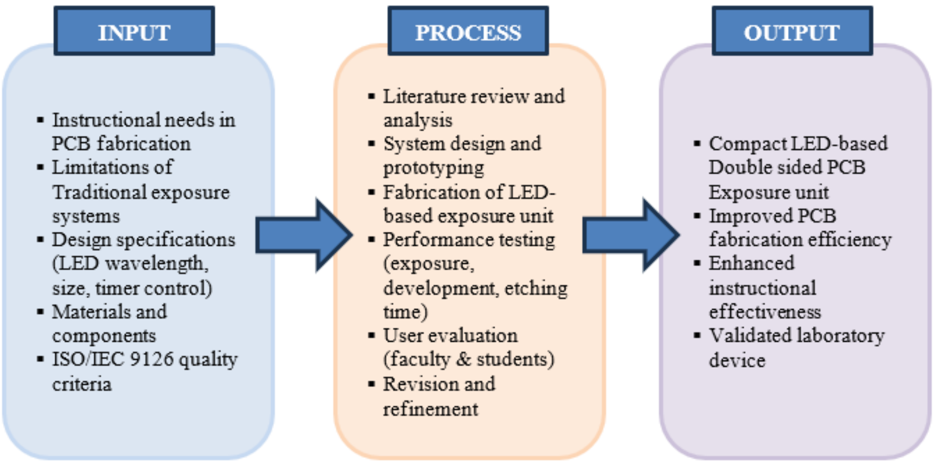

Figure 1. IPO Model of Compact LED-Based Double-Sided PCB Exposure Unit for Instructional Applications

The Input component in this research involves the technical needs, the instructional needs and the design needs that require to be established to create a small LED-based, double-sided PCB exposure unit. These inputs comprise of the known weaknesses of standard PCB exposure system, laboratory constraints in electronic classes, necessary PCB exposure parameters (wavelength compatibility with photoresist boards), materials available (LED arrays, timers, enclosure components), and quality assessment parameters, which are under the ISO/IEC 9126 model of product quality (International Organization for Standardization, 2001). Electronics engineering education also entails the instructional competencies which can be considered one of the vital inputs that meet the alignment between the learning outcomes and the device design.

The Process component adheres to the principles of the developmental research, the systematic analysis, design, developing, testing and refining of the instructional products (Richey, and Klein, 2007). It will start by reviewing the literature on related research and current technologies of PCB exposure. This is succeeded by the system design where the source is half LEDs, 2-sided alignment system, housing structure, and timing control combination. Manufacturing is done according to the approved specifications of designs. Performance testing measures the device regarding PCB exposure time, development time, etching time, and the largest board dimensions. The functionality, reliability, usability, maintainability, portability, operability and safety are evaluated using structured questionnaires to the user. The empirical findings are applied when making revisions in order to promote the efficiency of the devices and the instructional suitability.

The framework give an output of a tested miniature LED-based double-sided PCB exposure unit which can be used in laboratory instruction (Narendran, N., & Gu, Y.,2005). The anticipated results will be a higher PCB fabrication rate, a higher accuracy in double sided alignment, decrease in processing time, decrease in material wastage, and the enhancement of student learning. The framework presupposes that the purposeful developed and tested instructional machine will enhance laboratory performance and enhance practical competencies of students in PCB design and PCB modeling.

The study combines the principles of systems theory (Hall and Fagen, 1956) with principles of development research (Richey and Klein, 2007), and, thus, the developed PCB exposure unit will be technical and at the same time be pedagogically determined to fulfill the instructional goal.

Methodology

This research has used the Research and Development (R&D) technique of applying the ADDIE development model in designing, manufacturing, and testing of the LED-type type of printed circuit board (PCB) exposure unit, which was a double-sided one. Developmental research is suitable in the case of research that seeks to design, construct, validate, and refine an instructional tool or technological device as a result of systematic procedures of analysis, design, development, implementation, and assessment (Villanueva, 2017; Richey and Klein, 2007). ADDIE model offers a systematic and progressive model which maintains application of continuous refinement of the product made as a result of the empirical information and customer responses.

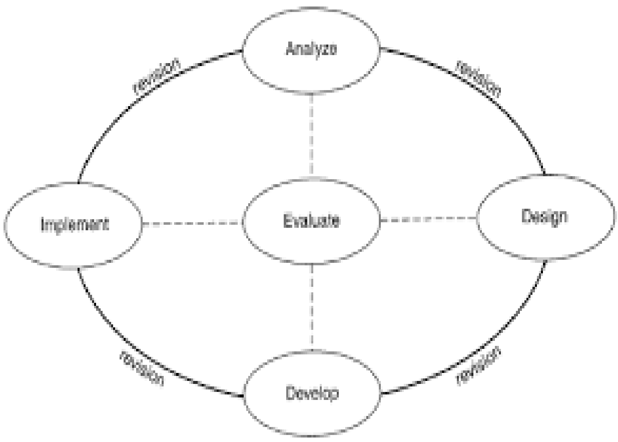

Figure 2. ADDIE Model (adapted from Branch, R. M. (2009); Molenda, M. (2015)

The study was conducted in accordance with the 5 stages of the ADDIE model:

1. Analysis Phase - This phase included analysis of related literature and available technologies of PCB exposure, identification of limitations of the traditional systems, and identification of requirements of instruction and technology to be used in the laboratory.
2. Design Phase – The system architecture was structured on the basis of the requirements achieved, covering LED system construction, dual sided positioning mechanism, shield system, and integration of a timer.
3. Development Phase – LED based double-side PCB exposure unit prototype was developed as per the design specifications that were predetermined. The individual parts were assembled, wired and set into functioning configuration.
4. Implementation Phase – The device developed was taken to field test in the laboratory to test its operational performance such as the PCB exposure time, the time taken to develop the device, the time taken to etch the board, and the size of the board the device could accommodate.
5. Evaluation Phase – There was both the technical and user evaluation of the device. The faculty members and electronics students were given a questionnaire that was structured to evaluate the system with regard to functionality, reliability, usability, maintainability, portability, operability, and safety. To present a check of the performance data and results of surveys conducted with the developed PCB exposure unit, statistical analysis was performed to

The research also involved descriptive research that was designed to measure quantitatively the device that was developed. A structured questionnaire was adopted as the main data-gathering tool and it was given to the members of the faculty, as well as to the electronics students. The tool evaluated the acceptability and the performance of the device according to the set quality standards. Technical performance results and survey data were statistically tested to reveal the effectiveness, reliability of the system and suitability of the system to instructional purposes.

Respondents of the Study

The respondents of this research were selected members of the faculty staff and students of the Electronics Department of the Bulacan State University - Main Campus and Bustos Campus. These subjects were selected to test the performance, functionality and teaching appropriateness of the designed compact LED based double sided PCB exposure module. Faculty members were involved because they have relevant knowledge on how to teach electronics and run laboratory operation whereas the selection of students was possible because they are the end-users of the device in PCB fabrication practice. Their combined opinion offered technical and education analysis of the composed system.

Table 1. Presents the distribution of respondents according to campus and classification.

Bulacan State University	No	Frequency	Description
Professors		21	The respondent faculty were instructors that dealt with laboratory-based courses such as electronics. They have been chosen depending on their knowledge and experience on PCB design, fabrication of circuits and teaching laboratories.
Main Campus	4		
Bustos Campus	17		
Students		24	The respondents included in the study were students on electronics courses as part of the Bachelor of Industrial Technology course. They were also the main end-users of the
Main Campus	7		
Bustos Campus	17		

Bulacan State University	No	Frequency	Description
			designed LED-based context of the PCB exposure unit which was developed as a double-sided model in laboratory processes.
Total No. of Respondents		45	

Research Instrument

An evaluation questionnaire based on ISO/IEC 9126 quality model was used as the principal tool of gathering the data in this research (Zeiss et al., 2008). Whilst the ISO/IEC 9126 was in fact designed with evaluation of software quality in mind, its systematic quality features were adjusted and contextualised to explore the performance and demurability of the developed LED-based double sided PCB exposure unit. Basically, ISO /IEC 9126 is a detailed guide towards assessing quality of products in terms of the specifications and sub-specifications. In the context of this research, the tool was modified to gauge the following aspects of quality: functionality, reliability, usability, maintainability, portability, operability and safety. These standards were correlated with the working and training needs of laboratory appliances in the field of electronics.

An electronic survey questionnaire was developed in accordance with these quality dimensions and administered on a structured survey questionnaire to various students of electronics and faculty members in the Electronics Departments of Bulacan State University - Bustos Campus and Main Campus. The respondents tested the PCB exposure unit developed on a Likert-scale format to establish the extent of its acceptability and instructional suitability. The instrument was revised before the learning process to give it relevancy in the evaluation of hardware-based learning and application, as well as in instruction.

Data Gathering Procedure

The concerned university authorities were contacted and formal permission was obtained to conduct the research before the research instrument was administered (Prince, M., 2004). A coordination with the respective college administrators and heads of departments was also done to ensure the right distribution and retrieval of the questionnaires. The Bulacan State University - Main Campus and Bustos Campus (Bulacan) were used in the study. The questionnaires were administered personally on the sampled faculty and electronics students by the researcher to ensure that the subjects had an understanding on the nature of the study as well as duly completed the instrument. The questionnaires handed out were all collected back after completion and this gave us a 100 percent response rate.

Data Processing and Statistical Treatment

The data obtained out of the survey questionnaires and performance testing were tabulated, tabulated, and realized out of descriptive statistics measures. Particularly, frequency counts, percentages, and weighted mean were applied to understand the responses of the participants on the acceptability and the performance of the developed compact LED-based dual sided PCB exposure unit. To summarize the results of the evaluation, descriptive statistics were utilized to identify the overall acceptability of the device according to the quality of a device based on the set criteria.

To guarantee the validity and accuracy of the calculated values, the researcher used the help of a qualified statistician to check the statistical calculation and interpretation of data.

The measurement of the degree of acceptability of the developed project was implemented on a five-point Likert scale. The respondents were required to rank their levels of agreement with each of the evaluative statements on a scale of agreement. The scale and the associated descriptive ratings will be given below:

Table 2. Five-point Likert scale for Acceptability

Scale	Range	Descriptive Rating
5	4.51 – 5.00	Very Acceptable
4	3.51 – 4.50	Acceptable
3	2.51 – 3.50	Moderately Acceptable
2	1.51 – 2.50	Unacceptable
1	1.00 – 1.50	Needs Improvement

Result and Discussion

To facilitate easy observation and methodical interpretation, the study findings are formatted in accordance with the specific objectives of the study that have been identified above. The design and the development process of the compact LED-based simple PCB exposure device of the second side is outlined in part one and part two. These paragraphs enlist the technical requirements, system design, production process, and mechanical architecture of the created instrument. The third section outlines the operational performance parameters of PCB exposure unit such as DC voltage output, current output, PCB exposure time, development time and etching time. The parameters were examined to identify the functional efficiency and technical capability of the system. The fourth part is the discussion on the assessment of the made device according to the acceptability of the quality of functionality, reliability, usability, maintenance, portability, operability, and safety. In this part will be presented the statistical report of the assessment of the respondents to ascertain the overall suitability of the instruction of the device.

Part I. The Design and Development of LED-type Double-sided PCB Exposure Box

Planning. Planning is the basis of every phase of designing and development process. The systematic approach of planning is necessary to make sure that the objectives of the project are clearly stated, the technical requirements are correctly analyzed, and the necessary assessment mechanisms are organized.

The researcher used a thorough analysis of requirements in this study to provide a clear picture in terms of specifications of LED-based double sided PCB exposure unit. The planning process was done to identify the target users (faculty and students in the electronics field), to determine the laboratory setting where the device would be used, the development standards that need to be used, and the criteria that would be used to evaluate the performance and acceptable nature of the system. This form of organization of the planning phase effectively outlined a well defined development framework to help in creating the PCB exposure unit as a teaching resource.

Design phase. The major goal of the design stage was to reduce identified user requirements into a functional prototype that would meet technical and instructional requirements. In this stage, the researcher identified the needed inputs, operational processes, as well as the expected outputs of the system in a systematic manner.

Design is an orderly and focused process that entails the establishment of the right strategies and elements in order to get certain aims and purposes. Within the framework of this paper, the design stage was concerned with producing a small LED-based exposure system that could expose pre-sensitized PCBs uniformly and in a shorter exposure time. Special care was developed so that the light distribution was consistent and efficient in timing control, and the alignment of both sides of boards was perfect.

The proposed LED based double sided PCB exposure unit will be used to handle the transfer of verified foil pattern layout onto pre-sensitized boards with enhanced efficiency and clarity. The quality of the exposure process lies in the correct positioning, maximum light intensity of LEDs, and regulated exposure time. Figures 3 - 6 show materials and parts that are needed to make the exposure unit.

Figure 3. Power Supply

The power supply unit supplies the measured direct current (DC) voltage to drive the timer module and LED system of indication. It is largely composed of isolation step-down circuit breaker, bridge rectifier circuit, filter circuit and voltage regulator. The isolation transformer is a step-down transformer which converts the standard 220 V alternating current (AC) input voltage to 15V AC with the current of one ampere. Such low voltage is now entered into a bridge rectifier circuit, which transforms the AC voltage into a pulsating DC voltage.

A filter capacitor is a 220 uF/25 V electrolytic capacitor. A 7812 voltage regulator integrated circuit (IC) is then used to stabilize the filtered DC voltage to produce a consistent 12V DC signal that is then used to power the timer and LED control circuitry. Also, the system includes a 10A, 220 V AC to 12 V DC relay that switches power and makes the exposure unit operation safe.

This regulated power supply configuration guarantees stable voltage output, protects sensitive components, and enhances the overall reliability and safety of the device.

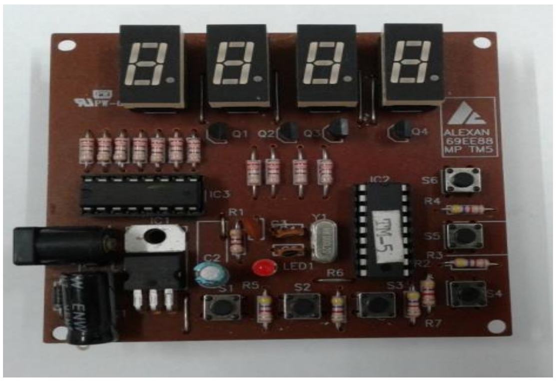

Figure 4. Timer (Alexan 69EE88 MP TM5)

The timer in Figure 4 module is a gadget that is followed to establish and manage the exposure of the printed circuit board (PCB). It also uses 9V to 12V DC power supply and features a number of functional switches to adjust and control the time. The switches perform the following functions:

- S2 switch – Starts the timer.
- S3 switch – Adds or measures the exposure time.
- S4 switch – Reset button or cancels the time.
- S5 switch – Reduces/ reduces the exposure time.
- S6 switch – Recalls or shows the time set before.

This timer system will help to have the correct exposure time of the PCB, thus the effect will be consistent and precise when using it in the laboratory.

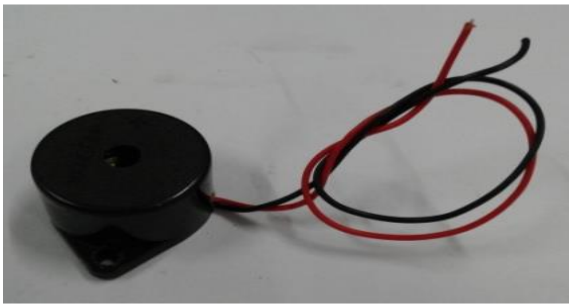

Figure 5. Buzzer

Figure 5, the buzzer, is an electrical device that transforms an electrical energy into a sound energy. In this project a Vansona type plastic buzzer with input voltage rate of 12V DC was employed. The buzzer is used as a sound alarm to indicate the end of the exposure cycle.

Figure 6. Light Emitting Diode Panel

Figure 6 is Light Emitting Diode (Que-LED) panel is an electric product that transforms electric energy to light energy. Its dimensions are 12 inches x 12 inches, its input is AC 175-220 V at 50 Hz, and power 12 watts.

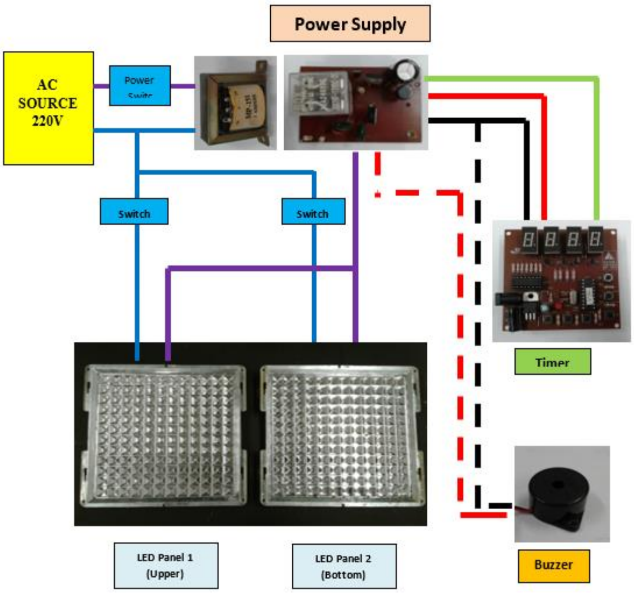

Figure 7. Pictorial Diagram of LED-type Double-sided PCB Exposure Box

Figure 7 demonstrates the electric connection between four key parts in the double-sided PCB exposure box i.e. power supply unit, timer unit, buzzer, and LED panels.

Part II. The Fabrication of LED-type Double-sided PCB Exposure Box

This stage is based on the objectives set by the project during the design stage. It entails actual building of the prototype based on the specification and conditions developed during stage of design. The resources and materials needed to carry out the construction of the project are locally obtained and can easily be accessed in the market. The assembly required will be in the form of tools and equipment that are usually available in normal electronics laboratories.

The PCB exposure unit was made and manufactured in two major steps as depicted in Figure 8.

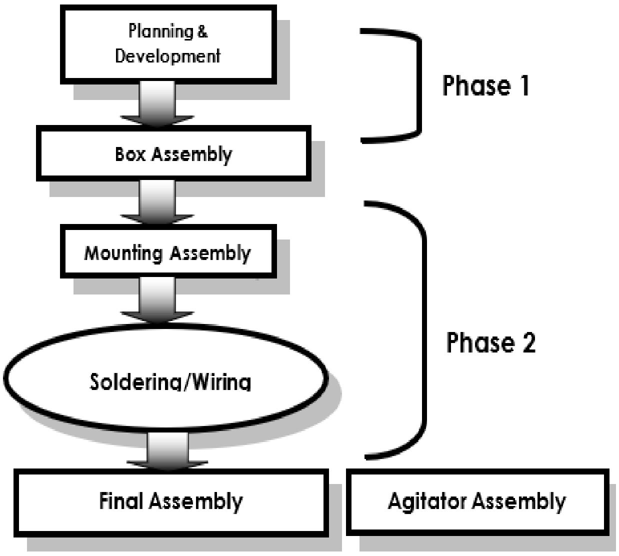

Figure 8. Fabrication and Construction Procedure of Printed Circuit Board Exposure Box

The printing circuit board (PCB) exposure box that was of the LED style was produced via three key processes which included: box assembly, component placement, and wire solder and an electrical connection.

Box Assembly

The preparation of all the necessary materials, tools and equipment will have to be made ready in order to assemble the enclosure properly. The main structural material was a 1/2-inch marine plyboard. The plywood was cut to size and marked in accordance with dimensions of plywood which was 51 cm x 33 cm x 13 cm. The stained parts were cut, and the edges were polished with the help of sandpaper to guarantee the clean and accurate finish.

Portable electric drill was used in making suitable kinds of openings in AC outlet, pilot lamp, independent switches, clear glass panel, and push buttons. A little wood epoxy was applied around the sides of the plywood panels and then the panels were nailed together to create a rectangular shape enclosure as per the required design.

The enclosure was then sliced into two parts when it is top and bottom according to the intended structure. Lastly, all the box was painted and left to dry so that it would not be used up in a short time and look like it was duct-taped.

Mounting Assembly

The first stage in the mounting assembly is to assemble all the required parts such as the LED lamps, power supply unit, glass panels, switches, buzzer, pilot lamp, handle and lock.

Fix the LED lamps in the upper and bottom section of the enclosure using the right screws to firmly fix the lamps in place. Install the LEDs

After attaching the LED lamps place the 1/8-inch glass panel over each assembly of the LED keeping a clearance distance of about 1.5 inches to ensure an even distribution of light and protection. Fit the glass panel with a screw. The same thing happens with the bottom part of the box.

The second step is to mount the power supply unit, micro switch, multi-purpose timer, and control switches, mini-buzzer, and pilot lamp as per the approved layout plan. No matter what, make sure that everything is into place and is firmly attached to it before wiring connections.

Agitator Assembly

This step is that of integrating all the parts and testing the system on a full scale. Figure 9 demonstrates the completed assembly parts of the LED-based two sided PCB exposure unit part, and Figure 10 displays the parts as the agitator box that were assembled in the PCB development and etching phases.

Fit the synchronous AC motor into the specially designed enclosure or housing. Connect the main switch and the light signifier to be able to control the power supply and monitor the functioning. Connect plastic rotator to the shaft of synchronous motor that acts as the agitator in the PCB development and etching stages.

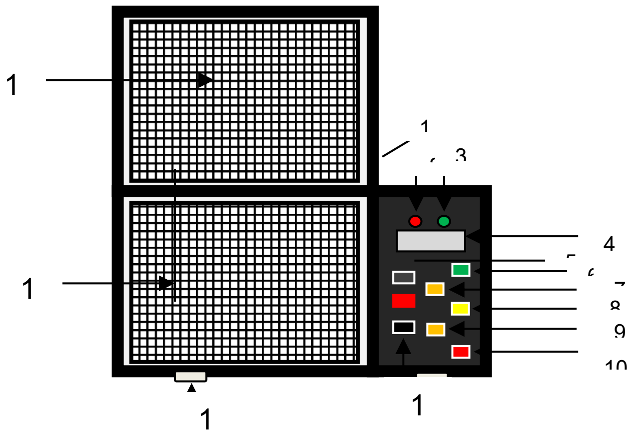

Figure 9. LED-TYPE DOUBLE-SIDED PCB EXPOSURE BOX (Top View)

Parts Description
1. S1 POWER SWITCH (On/Off)
2. LED 1 Red (Light Emitting Diode)
3. LED 2 Green (Light Emitting Diode)
4. LED 3 Timer Display
5. S 1LP Switch LED panel 1
6. S2 Switch (start)
7. S3 Switch (count up)
8. S4 Switch (stop)
9. S5 Switch (countdown)
10. S6 Switch (Recall)
11. S2LP Switch LED panel 2
12. PL Panel lock
13. LP1 LED Panel 1
14. LP2 Led Panel

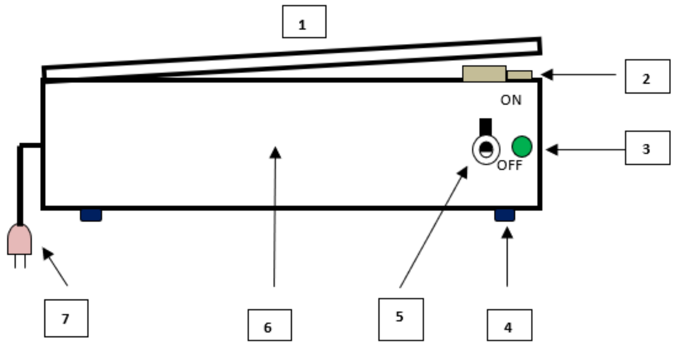

Figure 10. AGITATOR BOX (Front View)

Legend:

1	Top panel
2	Synchronous motor (30-36 R/Min) AC 220-240 volts
3	Power LED indicator
4	Plastic footing
5	Power switch (ON/OFF)
6	Case
7	Cord set

After assembling, the prototype was tested to ensure that it is operational. Extensive testing was done to make sure that everything was in the right working condition and safe. The testing process implied an exposure of the PCBs of different sizes and circuit design to examination several times to see the consistency of the system, its reliability, and the performance in general.

Part III. Capabilities of the LED-type Double-sided PCB Exposure Box

The reviewing and modification process is a methodological procedure getting performed in order to discover the quality of operation and the performance capabilities of the developed apparatus. Assessment is done at every development stage to ensure that the set goals are attained and also to show where improvements are needed. There is continuous testing, which will identify areas of weaknesses and rectify before the final implementation. This is an iterative process that enhances the level of technical performance as well as the teachability of the project.

After the fabrication was finished, the LED-based double sided PCB exposure unit passed through a number of tests on functionality and performance. A 3 x 2.5-inch PCB was chosen with a pre-sensitized (using the plates) through pre-sensitization of the entire PCB using a pre-sensitizer instead of individual plates, and placed on the transparent glass exposure surface in the initial testing procedure. The system used two 12 watt LED lamps which were gas controlled by separate switches so that each pin in the parallel system would give the same light.

In the initial experiment, exposure was adjusted to 30 seconds which managed to obtain a good and resolved circuit pattern. A second trial was done with 20 seconds exposure time to further optimize the performance of the system and enhance processing efficiency. The findings showed that the exposure setting of 20 seconds had equal clear and well-defined circuit traces before the etching process. This modification showed a higher time-saving and did not affect the quality of output.

The clarity of exposed light proved satisfactory that the LED cluster provided a sufficient amount and uniform level of light intensity required to process pre-sensitized PCBs. It is also an indicator of the capability of the device to improve the efficiency of the laboratory when performing instructional activities as the time spent on the exposures reduced.

Table 3 shows the average time of the exposure, development, and etching processes of single-sided and the etching of the PCBs with different sizes on the panel. These findings offer quantifiable information on the system and its ability to work and its ability to maintain a consistent performance.

Table 3. Processing time for Single-sided and Double-sided PCB

PCB SIZE (Inches)	SINGLE-SIDED PCB			DOUBLE-SIDES PCB		
	Exposure time (seconds)	**Develop-ment time (seconds)**	**Etching time**	**Exposure time (seconds)**	**Development time (seconds)**	**Etching time**
2 x 4	20	140	11 mins and 59 sec	20	145	12 mins and 45 sec
3 x 4	20	153	12 mins and 50 sec	22	155	13 mins and 20 sec
4 x 4	22	170	13 mins and 30 sec	23	181	13 mins and 40 sec
4 x 6	25	205	15 mins and 25 sec	22	210	15 mins and 30 sec
4.5 x 8	23	220	18 mins and 50 sec	25	230	18 mins and 58 sec
Average	22	117.6	14 mins and 31 sec	22.4	184.2	14 mins and 50 sec
	Average processing time: 17 mins and 50 sec			**Average processing time: 18 mins and 16 sec**		

Part IV. Evaluation of Project Acceptability

This section outlines the results of the evaluation of the designed compact LED-based, double-sided PCB exposure unit as far as the following quality characteristics are considered; (1) functionality, (2) reliability, (3) usability, (4) maintainability, (5) portability, (6) operability and safety.

The summary of the respondents evaluations in the acceptability of the developed project is presented in Table 4 according to the seven criteria identified.

Table 4. Summary of Respondents' Evaluation of Project Acceptability

Criteria	Mean	Interpretation
Functionality	4.79	Very Acceptable
Reliability	4.76	Very Acceptable
Usability	4.82	Very Acceptable
Maintainability	4.74	Very Acceptable
Portability	4.74	Very Acceptable
Operability	4.85	Very Acceptable
Safety	4.74	Very Acceptable
Grand Mean	**4.78**	**Very Acceptable**

Table 4 revealed that all quality criteria were rated as Very Acceptable with variable scores of between 4.74 and 4.85 which shows that there is a high degree of satisfaction among the respondents. On operability, the score had the best mean of 4.85, implying that the respondents were comfortable with how easy the device is to operate and that the device is labworthy. This was succeeded by usability (M = 4.82), functionality (M = 4.79), which once again confirms the fact that the system does the functions that it is supposed to do well and it is easy to use.

At the same time, each of the mean scores of maintainability, portability, and safety saw a 4.74 mean score, which once again lies under the range of Very Acceptable. These findings suggest that the equipment is deemed safe, controllable and portable to be used in teaching electronics laboratories.

On the whole, the developed LED-based double-sided PCB exposure unit had a grand mean of 4.78 which shows a performance of Very Acceptable. The results imply the possibility and existence of moving the device and adopting it to improve instruction in Electronics courses (processes related to the process of PCB fabrication and etching). The ability of the system to satisfy both technical and instructional requirements, as indicated by the high ratings in all dimensions of quality, implies that the laboratory may be utilized in the application of the system.

Conclusion

In accordance with the results of the research, the following conclusions are made:

The tested compact LED based PCB exposure unit was developed in the form of a double-sided PCB and was found to be fully satisfactory to the faculty members and students of electronics at the University. The appliance scored very well in all the evaluated quality parameters which include; functionality, reliability, usability, maintainability, portability, operability and safety. Such findings demonstrate that the system is efficient in providing technical performance requirements as well as the instructional needs of use in laboratories.

In addition to this, the exposure unit of the PCB developed becomes useful to the University, to the faculty, and student of the Bachelor of Industrial Technology (BIT) major in Electronics. The technology improves the way a teaching is provided by easing the process of PCB fabrication, increasing the efficiency of its functioning, and assisting the practical laboratory learning. The way it is adopted in courses of electronics can help to enhance student competency in PCB design and etching processes and can prove to be a cost-effective and useful instructional tool.

All in all, the paper confirms that compact LED-based double-sided PCB exposure unit is an acceptable and useful laboratory tool to be used in teaching electronics.

Recommendation

By the substantial research results and conclusions in this study, the following are the research recommendations that are earnestly proposed:

1. For the College of Industrial Technology, there is a suggestion that the prototype of the compact LED-based double sided PCB exposure unit be fully implemented into the laboratory teaching. It can be done in seminar-workshops and under practice training sessions that can inform and accustom faculty members and students on how the device should be operated, maintained and be safe.
2. For potential manufacturers and industry partners, the mass production of the device can be regarded as the benefit to academic electronics laboratory providers due to the potential manufacturers and industry collaborators. With its lecturing significance, as well as practice, the device has potential as a low priced laboratory apparatus in electronics courses.
3. For future system enhancement, the handle of the system should also be considered in a future upgrade; this can be to a more stable material like metal because it will help to enhance the system in terms of portability and structural stability.
4. For future researchers, it is suggested also to install exhaust or cooling fan to increase the airflow in the power supply system and the thermoregulation in the working conditions when it is used a long time.

References

Branch, R. M. (2009). *Instructional design: The ADDIE approach*. Springer. https://doi.org/10.1007/978-0-387-09506-6

Department of Trade and Industry. (2023). *Philippine electronics industry profile 2023*. https://www.dti.gov.ph

Hall, A. D., & Fagen, R. E. (1956). Definition of system. *General Systems, 1*, 18–28.

International Organization for Standardization. (2001). *ISO/IEC 9126-1:2001 software engineering—Product quality—Part 1: Quality model*. https://www.iso.org/standard/22749.html

International Organization for Standardization. (2011). *ISO/IEC 25010:2011 systems and software engineering—Systems and software quality requirements and evaluation (SQuaRE)— System and software quality models*. https://www.iso.org/standard/35733.html

Mahmud, W. A. W. (2023). UV LED printing device for PCB fabrication: Design and testing of a portable LED-based exposure system for educational settings. *Journal of World Engineering Research and Development*. https://journals.hh-publisher.com/index.php/JWER/article/view/1077

Molenda, M. (2015). In search of the elusive ADDIE model. *Performance Improvement, 54*(2), 40–42. https://doi.org/10.1002/pfi.21461

Narendran, N., & Gu, Y. (2005). Life of LED-based white light sources. *Journal of Display Technology, 1*(1), 167–171.https://doi.org/10.1109/JDT.2005.852510

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education, 93*(3), 223–231. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x

Rao, D. A. V. (1987). PCB design and process techniques. *IETE Journal of Education, 28*(1), 10– 21. https://doi.org/10.1080/09747338.1987.11436133

Richey, R. C., & Klein, J. D. (2007). *Design and development research: Methods, strategies, and issues*. Lawrence Erlbaum Associates. https://doi.org/10.4324/9780203826034

Richey, R. C., & Klein, J. D. (2014). Design and development research. In J. M. Spector et al. (Eds.), *Handbook of research on educational communications and technology* (4th ed., pp. 141–150). Springer. https://doi.org/10.1007/978-1-4614-3185-5_12

Schubert, E. F. (2018). *Light-emitting diodes* (3rd ed.). Cambridge University Press. https://doi.org/10.1017/9781108278034

Selver, E. (2025). Recent developments in sustainable components affecting printed circuit board technologies. *Macromolecular Materials and Engineering*. https://doi.org/10.1002/mame.202500311

Sharma, P. (2022). *PCB design for absolute beginners* (1st ed.). Apress. https://doi.org/10.1007/978-1-4842-8040-9

Villanueva, A. T. A. (2021). *Energy conservation system for classroom using microcontroller: An innovation*. ProQuest Dissertations & Theses Global. https://www.proquest.com/openview/aa76c361cce61ffc963662ea0cad3c18

Williams, T. (2020). Advances in PCB prototyping techniques for engineering education laboratories. *International Journal of Engineering Education, 36*(4), 1256–1265.