

ANALYSIS OF FAILURE FACTORS IN RUNNING LED CIRCUIT ASSEMBLY USING BREADBOARD AND PCB AMONG VOCATIONAL ELECTRONICS ENGINEERING STUDENTS

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Abstract. Running LED circuit assembly is a widely implemented introductory practicum module in vocational electronics engineering education, yet students consistently encounter operational failures during assembly activities using both breadboard and PCB media. This study aimed to analyze the dominant failure factors in running LED circuit assembly and compare operational failure tendencies between breadboard and PCB media among vocational electronics engineering students. A quantitative descriptive survey was conducted using a five-point Likert-scale questionnaire distributed to 50 students at Sriwijaya State Polytechnic. Results indicated that in breadboard assembly, damaged components and IC overheating was the dominant failure factor ($M = 3.54$), followed by incorrect polarity installation ($M = 3.30$) and incorrect wiring ($M = 3.24$). In PCB assembly, broken copper traces and open circuit defects dominated ($M = 3.62$), followed by solder bridge defects and incorrect component placement ($M = 3.50$). Comparative analysis revealed that PCB assembly demonstrated a higher overall operational failure tendency than breadboard assembly, with mean scores of 3.10–3.18 versus 2.86–2.92 respectively. These findings suggest that breadboard failures are predominantly reversible and rooted in power mishandling, while PCB failures are largely permanent and driven by fabrication process execution. Practicum instruction should prioritize power supply verification for breadboard and etching process control for PCB assembly.

1. INTRODUCTION

Vocational electronics engineering education relies heavily on laboratory practicum activities to connect theoretical knowledge with direct circuit implementation. Hands-on assembly tasks develop core student

competencies such as component identification, schematic interpretation, soldering, wiring, and fault isolation [1], [2]. Among the introductory practicum modules commonly conducted in vocational electronics programs, the running LED circuit holds a prominent position because

its configuration is straightforward, its operational cost is low, and its sequential visual output allows students to observe circuit responses directly without requiring additional measurement instruments. The choice of assembly medium in practicum activities has been shown to influence student understanding of fundamental circuit concepts such as current flow, polarity, and component connection configuration [3]. The circuit typically combines the NE555 timer configured in astable mode with the CD4017 decade counter to generate a sequential LED switching pattern [4], [5]. This combination allows students to simultaneously observe analog pulse generation and digital counter logic within a single practical exercise, making the running LED circuit an effective entry-level platform for developing circuit assembly and diagnostic skills. The schematic diagram of the running LED circuit used in this study is presented in Fig. 1.

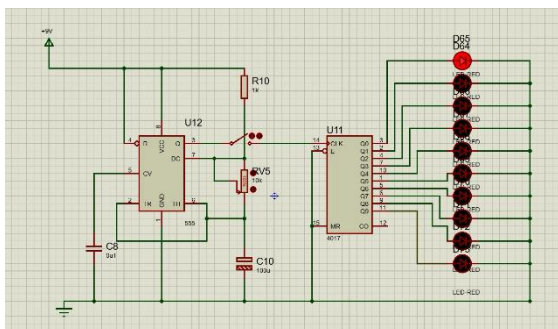


Fig. 1. Schematic Diagram of Running LED Circuit using NE555 Timer and CD4017 Decade Counter Designed in Proteus 8 Professional

In breadboard implementation, assembly failures most commonly originate from misinterpretation of internal breadboard connection paths, incorrect wiring, improper IC pin placement, and polarity reversal of electronic components [1], [6]. The three-dimensional grid configuration of the breadboard, where insulated jumper wires cross and overlap in multiple directions, has been shown to complicate students' understanding of connection paths and increase the likelihood of assembly errors [3]. Loose jumper connections and unstable contact resistance can also cause intermittent circuit behavior that is difficult to trace during troubleshooting. A less

immediately obvious but significant failure source is component damage resulting from sustained overheating, which occurs when reversed supply connections or undetected short circuits expose the NE555 or CD4017 to thermal stress beyond rated operating conditions [7], [8]. Because breadboard connections are non-permanent, most of these failures can be corrected by rewiring or component replacement without affecting the board itself. Troubleshooting activities have also been recognized as a central learning outcome in electronics laboratory education, as they develop students' diagnostic reasoning and systematic fault isolation skills during practical assembly tasks [2], [9].

PCB-based assembly presents a different set of challenges. Fabrication defects introduced during the etching process, including inter-trace short circuits from incomplete ferric chloride etching and broken copper traces from excessive chemical exposure, represent the most critical failure sources in student-produced PCBs [10], [11]. Solder bridge defects and poor soldering quality further reduce electrical reliability by creating unintended conductive paths or weak mechanical joints [12]. Unlike breadboard faults, PCB fabrication defects are permanent and require physical repair rather than simple rewiring, making PCB assembly considerably more demanding in terms of troubleshooting effort. These types of conductive and structural defects in PCB are well-documented in literature on PCB quality inspection and defect analysis [12], [13].

Existing research in this area has addressed PCB defect detection from an industrial inspection perspective, with many studies developing automated optical inspection systems, image-processing algorithms, and deep learning-based classifiers for identifying fabrication defects at a manufacturing scale [12], [13], [14], [15]. Troubleshooting instruction in electronics laboratory courses has also received scholarly attention, with studies examining how instructors teach fault isolation

strategies and how students develop diagnostic reasoning during practicum activities [2], [9]. However, these studies focus predominantly on industrial environments or general electronics laboratory settings rather than on vocational-level practicum activities. To date, no study has specifically compared the dominant failure factors between breadboard and PCB assembly in the context of running LED circuit fabrication by vocational electronics engineering students. The quantitative relationship between assembly medium and operational failure tendency in this educational context also remains unexplored.

This study addresses that gap by analyzing the dominant failure factors encountered during running LED circuit assembly using both breadboard and PCB media among vocational electronics engineering students at Sriwijaya State Polytechnic. A quantitative survey approach was employed, using a frequency-based Likert-scale questionnaire distributed to 50 students who had completed both types of practicum activities. The study investigates failure indicators including wiring errors, polarity reversal, soldering defects, schematic misinterpretation, IC pin misidentification, incorrect component installation, and inter-trace short circuits. Three research questions guide the investigation: (1) What factor predominantly causes running LED circuit failure in breadboard assembly? (2) What factor predominantly causes running LED circuit failure in PCB assembly? and (3) Which assembly medium demonstrates a higher operational failure tendency among students? The findings are intended to provide practical guidance for improving troubleshooting instruction, practicum procedure design, and circuit assembly training in vocational electronics laboratory education.

2. LITERATURE REVIEW

2.1 Electronics Laboratory Education and Assembly Media

Electronics laboratory education occupies a central role in vocational engineering programs because it bridges the gap between abstract circuit theory and the physical reality of working electronic systems. Unlike purely theoretical instruction, laboratory practicum activities require students to translate schematic representations into functional circuits, manage real component tolerances, and respond to unexpected operational faults in real time [1], [2]. This direct engagement with physical hardware develops a category of technical competence that cannot be replicated through simulation or passive observation alone. Within vocational electronics programs specifically, the quality of practicum instruction and the choice of assembly medium have been shown to significantly influence both learning outcomes and the frequency of assembly-related failures encountered by students [2], [16].

Two assembly media are most commonly employed in vocational electronics laboratory activities: the solderless breadboard and the printed circuit board. Breadboards allow non-permanent component placement and rapid circuit reconfiguration, making them well-suited for iterative prototyping and fault correction during the learning process [16]. PCBs, by contrast, provide a more permanent assembly platform where copper traces replace jumper wires and soldered joints replace clip connections, resulting in circuits that more closely resemble real-world electronic products. Pepler et al. [3] demonstrated through comparative analysis that the material properties of different circuitry assembly media directly shape students' understanding of circuit concepts, including current flow comprehension, polarity recognition, and layout design principles. Their findings indicated that breadboards and paper circuit media produced measurably different learning trajectories for the same circuit concepts, underscoring that the

choice of medium is not pedagogically neutral. This relationship between assembly medium and learning outcome provides the foundational rationale for investigating how each medium generates distinct failure patterns in vocational electronics practicum contexts.

2.2 Failure Factors in Breadboard-Based Circuit Assembly

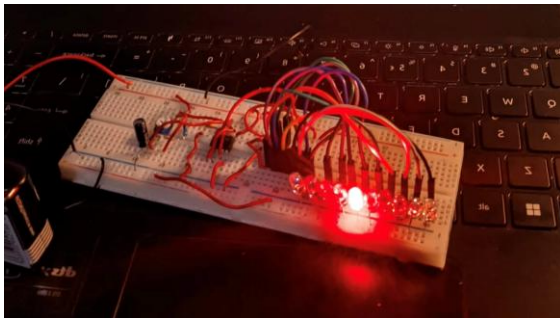


Fig. 2. Breadboard Assembly of The Running LED Circuit During Practicum Activities

The breadboard assembly of the running LED circuit conducted during practicum activities is presented in Fig. 2. Breadboard-based circuit assembly, despite its non-permanent and reconfigurable nature, presents several recurring failure patterns that have been documented across multiple studies in electronics education research. Alessandrini [1] investigated how undergraduate design students approached wiring problems during electronic circuit prototyping on breadboards, finding that connection mapping errors were the most frequently occurring failure type. Students consistently misidentified internal breadboard connection paths, particularly at the junction between horizontal rows and vertical power rails, leading to open circuit conditions and unintended short circuits. The study also noted that as circuit complexity increased beyond a single functional block, the frequency of wiring errors increased disproportionately, suggesting that breadboard layout comprehension does not scale linearly with student experience. In a related study, Alessandrini [17] observed that wiring errors and improper connection mapping during breadboard-based electronic prototyping

were frequently compounded by students' failure to systematically verify each connection before powering the circuit, resulting in repeated component stress and increased likelihood of IC damage during fault diagnosis attempts.

Bianchi et al. [16] further examined breadboard assembly in the context of remote and synchronous physical computing education, reporting that unstable contact resistance caused by loose jumper placement was a persistent source of intermittent circuit behavior. Unlike permanent connection failures, intermittent faults caused by loose jumpers are particularly difficult to diagnose because they may appear functional during initial testing but fail under slight mechanical disturbance. This category of failure is especially problematic in running LED circuit assembly, where the NE555 timer and CD4017 counter must maintain stable power and signal connections throughout sequential operation. Beyond connection-related failures, component-level damage resulting from polarity reversal and IC overheating has been identified as a significant contributor to circuit malfunction in student assembly activities [6], [7]. Zhong and Walther [6] reported that LED-based circuits are particularly sensitive to reversed polarity connections, which can permanently damage both the LED components and associated drive circuit elements including integrated circuits. Yao et al. [7] similarly documented that thermal stress caused by sustained overcurrent or reverse bias conditions accelerates LED package degradation and increases failure probability in circuit assemblies operating outside rated conditions.

2.3 PCB Fabrication Defects and Electrical Reliability



Fig. 3. Printed Circuit Board (PCB) Assembly of The Running LED Circuit During Practicum Activities

The PCB assembly of the running LED circuit conducted during practicum activities is presented in Fig. 3. PCB-based assembly shifts the primary failure locus from connection configuration to fabrication quality. The wet chemical etching process used in student-level PCB production relies on ferric chloride solution to selectively remove exposed copper from the board substrate, leaving only the intended circuit traces. Atta [11] conducted an experimental investigation into the effect of process parameters on copper trace quality during FeCl_3 etching, demonstrating that insufficient agitation, incorrect solution concentration, and inadequate immersion time collectively produce incomplete etching — a condition where residual copper between adjacent traces forms unintended conductive bridges. These inter-trace short circuits disrupt the logical operation of sequential circuits such as the running LED configuration, where the CD4017 counter output depends on electrically isolated signal lines to control individual LED channels independently. Park et al. [10] identified similar fabrication-stage defects in the context of PCB solder process reliability, noting that conductive contamination between traces significantly reduces circuit yield in both industrial and educational manufacturing environments.

Soldering quality represents the second critical failure domain in PCB assembly. Solder bridge defects occur when excess solder flows between adjacent pads or traces during the hand-soldering process, creating low-resistance conductive paths that effectively short-circuit the connected nodes. Chen et al. [8] demonstrated that solder joint integrity in high-power component packages degrades progressively under repeated thermal cycling, with joint failure accelerating when assembly conditions deviate from rated thermal specifications — a pattern directly relevant to student PCB assemblies where soldering consistency is rarely maintained across all joints. Poor solder joint formation, including cold solder joints characterized by insufficient wetting and crystalline surface texture, produces high-resistance connections that may initially appear functional but degrade under thermal cycling or mechanical stress [12]. Ling and Isa [12] categorized these defect types — including open circuits, solder bridges, insufficient solder, and component misalignment — as the primary quality failure modes in PCB assembly across both industrial and educational production contexts.

2.4 PCB Defect Detection: Industrial Approaches and Their Limitations

The detection and classification of PCB defects has attracted substantial research attention, with recent studies focusing heavily on automated optical inspection and machine learning-based approaches. Ling and Isa [12] surveyed PCB defect detection methods spanning traditional image processing, classical machine learning, and deep learning frameworks, concluding that convolutional neural network-based architectures consistently outperformed threshold-based and template-matching methods in detection accuracy across standard defect categories. Chen et al. [13] proposed a comprehensive deep learning framework for PCB defect classification, achieving high

accuracy across six defect types including open circuits, solder bridges, and missing components under controlled laboratory conditions. Anoop et al. [14] reviewed earlier image processing approaches to PCB defect detection, identifying morphological segmentation and template subtraction as foundational techniques that preceded modern deep learning methods. Bhattacharya and Cloutier [15] extended this line of research by demonstrating that end-to-end deep learning pipelines could achieve robust classification performance even with limited training data when transfer learning strategies were applied.

While these technological advances demonstrate strong detection performance in industrial settings, their direct applicability to vocational electronics laboratory contexts is substantially limited. Industrial PCB inspection systems are designed to detect defects in mass-manufactured boards produced under controlled process conditions with tight dimensional tolerances, whereas student-produced PCBs are fabricated under variable conditions with manual etching, hand soldering, and non-standardized layout designs. The defect profiles of student-produced PCBs — characterized by irregular trace geometries, variable solder joint quality, and process-dependent etching outcomes — differ meaningfully from the standardized defect categories used to train and evaluate industrial inspection models [11], [14]. More critically, these automated detection systems address defect identification after fabrication is complete, whereas the more pressing educational challenge lies in preventing fabrication errors during the assembly process itself. This distinction reveals a significant gap between what industrial PCB inspection research has achieved and what vocational electronics education actually requires.

2.5 Troubleshooting Instruction and Research Gap

Troubleshooting competency has been identified as a central yet frequently under-addressed learning outcome in electronics laboratory education. Van De Bogart et al. [9] investigated metacognitive processes during collaborative circuit troubleshooting, finding that students who engaged in structured diagnostic discussion demonstrated significantly improved fault identification accuracy. Their analysis revealed that effective troubleshooting in electronics laboratory settings requires not only technical knowledge of circuit operation but also deliberate metacognitive monitoring — the ability to recognize when one's current diagnostic strategy is not producing useful information and to systematically shift approaches. Dounas-Frazer and Lewandowski [2] examined how electronics laboratory instructors approach troubleshooting instruction, finding considerable variation in pedagogical strategy. Many instructors relied on implicit modeling — demonstrating troubleshooting behavior without explicitly articulating the underlying diagnostic reasoning — which limited students' ability to internalize transferable fault isolation strategies applicable across different circuit configurations and assembly media.

Despite the growing body of research on PCB defect detection, troubleshooting instruction, and breadboard-based prototyping failures, a specific and practically significant gap remains unaddressed in the literature. Existing studies on PCB failures focus predominantly on industrial manufacturing environments, automated inspection technologies, or controlled experimental settings rather than on the practical assembly failures encountered by vocational electronics engineering students during laboratory practicum activities. Studies on breadboard failures similarly tend to focus on general electronics education contexts without distinguishing between different circuit

types or examining how failure patterns in breadboard assembly compare quantitatively with those in PCB assembly for the same circuit module. No study has specifically analyzed and compared the dominant failure factors between breadboard and PCB assembly in the context of running LED circuit fabrication at the vocational level, nor has any study quantitatively determined which assembly medium presents a higher operational failure tendency among students in this educational setting. This study directly addresses these gaps through a questionnaire-based quantitative analysis of failure factor frequency across both assembly media.

3. METHODOLOGY

This study employed a quantitative descriptive survey design to analyze the dominant failure factors encountered during running LED circuit assembly using breadboard and PCB media among vocational electronics engineering students. A quantitative approach was selected because the study required numerical measurement of failure frequency across a defined set of assembly indicators, enabling systematic comparison between two assembly media without relying on subjective interpretation. Creswell [18] described quantitative research as an approach in which the investigator uses numerical data to test or measure variables, examine relationships, and explain observed phenomena through statistical procedures. The descriptive survey design was considered most appropriate for this study because it allowed failure frequency patterns to be captured directly from students who had completed both breadboard and PCB assembly activities, without introducing experimental manipulation that would not reflect authentic practicum experiences. The research procedure is illustrated in Fig. 4.

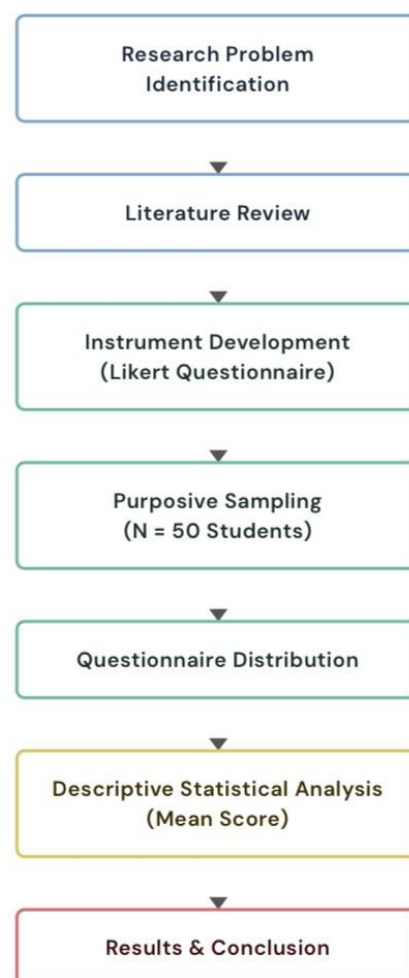


Fig. 4. Research Methodology Flowchart

The primary data collection instrument was a structured questionnaire organized around three thematic areas: failure factors in breadboard assembly, failure factors in PCB assembly, and comparative operational failure tendencies between the two media. The questionnaire adopted a five-point frequency-oriented Likert scale with response options of Never, Rarely, Sometimes, Often, and Very Often, scored from 1 to 5 respectively. Cohen et al. [19] noted that Likert-scale questionnaires are well-suited for survey-based educational research because they capture variation in respondent experience along a continuous frequency spectrum rather than forcing binary responses. The breadboard-specific failure indicators covered wiring errors, polarity reversal, incorrect component

installation, improper IC pin placement, schematic interpretation errors, loose jumper connections, unstable power supply connections, and incorrect component values. The PCB-specific indicators addressed solder bridge formation, broken copper traces, inter-trace short circuits, PCB etching defects, poor soldering quality, and PCB layout errors. An additional comparative item set was included to assess which assembly medium demonstrated a higher operational failure tendency among respondents.

The study was conducted at Sriwijaya State Polytechnic, involving students from the Electronics Engineering study program who had participated in laboratory practicum activities involving running LED circuit assembly. A total of 50 students were selected as respondents through purposive sampling. Etikan et al. [20] defined purposive sampling as a non-probability technique in which participants are deliberately selected based on characteristics directly relevant to the research objectives. The selection criterion applied was that respondents must have participated in electronics laboratory practicum activities involving running LED circuit assembly using breadboard or PCB. All respondents were retained in the analysis based on their practical assembly experience relevant to the failure indicators under investigation, even though not all respondents had experience with both media simultaneously.

The questionnaire was distributed directly to respondents following the completion of their laboratory practicum activities, ensuring that responses reflected recent and concrete assembly experience. After data collection was completed, responses were analyzed using descriptive statistical procedures including frequency distribution, percentage calculation, and mean score computation for each questionnaire item. Mean scores were interpreted against the five-point Likert scale,

where scores in the 4.00–5.00 range indicated that a failure factor occurred Often to Very Often, scores in the 3.00–3.99 range indicated Sometimes to Often, and scores below 3.00 indicated that the factor was Rarely experienced among respondents. The failure factor with the highest mean score within each medium was identified as the dominant failure indicator for that medium. Creswell [18] confirmed that descriptive statistical analysis is appropriate for identifying patterns in quantitative survey data and presenting findings in a form that directly addresses the stated research questions. Mean score comparison across the comparative item set was used to determine which assembly medium demonstrated the higher overall operational failure tendency among vocational electronics engineering students.

4. RESULT AND DISCUSSION

This study analyzed failure factors encountered during running LED circuit assembly among 50 vocational electronics engineering students using breadboard and PCB media. Results are organized based on the three research questions stated in the introduction.

Table I presents respondents' prior assembly experience. Of the 50 respondents, 47 students (94%) had previously assembled a running LED circuit using a breadboard, while 49 students (98%) had done so using PCB. This confirmed that the respondent sample possessed sufficient practical experience with both media to provide meaningful responses to the failure factor questionnaires.

Table I. Students' Responses to the Experience in Running LED Circuit Assembly

No	Question	Yes	No
1	Have you ever assembled a running LED circuit using a breadboard?	47 (94%)	3 (6%)
2	Have you ever assembled a running LED circuit using a PCB?	49 (98%)	1 (2%)

4.1 Failure Factors in Breadboard Assembly

Table II presents the full distribution of student responses across ten breadboard failure indicators. Among these, damaged components and IC overheating recorded the highest mean score ($M = 3.54$), placing it in the Sometimes-to-Often frequency range. Incorrect polarity installation followed at $M = 3.30$, and incorrect wiring on the breadboard at $M = 3.24$. A notable pattern in the data was that hardware-level failures ranked higher than connection-based errors such as wiring mistakes or misinterpretation of breadboard connection paths. The dominant failure factors are summarized in Table III. The mean scores of all breadboard failure factors are illustrated in Fig. 5.

Table II. Students' Responses to the Failure Factors in Breadboard Assembly

No	Statement	N	R	S	O	VO
1	Incorrect wiring installation on the breadboard caused the running LED circuit to malfunction.	0 (0%)	9 (18%)	25 (50%)	11 (22%)	5 (10%)
2	Misinterpretation of schematic diagrams caused assembly errors on the breadboard.	5 (10%)	7 (14%)	22 (44%)	10 (20%)	6 (12%)
3	Incorrect IC pin placement caused operational problems in the running	6 (12%)	10 (20%)	14 (28%)	8 (16%)	12 (24%)

4	LED circuit. Incorrect polarity installation of electronic components caused the circuit to operate improperly.	3 (6%)	8 (16%)	19 (38%)	11 (22%)	9 (18%)
5	Loose jumper wire connections caused instability in the running LED circuit.	3 (6%)	10 (20%)	16 (32%)	18 (36%)	3 (6%)
6	Misunderstanding of breadboard connection paths caused circuit assembly errors.	2 (4%)	10 (20%)	20 (40%)	11 (22%)	7 (14%)
7	The use of incorrect component values caused disruptions in circuit operation.	4 (8%)	5 (10%)	23 (46%)	15 (30%)	3 (6%)
8	Damaged components or overheated IC caused operational failure in the circuit.	2 (4%)	4 (8%)	19 (38%)	15 (30%)	10 (20%)
9	Unstable power supply connections affected the performance of the	3 (6%)	8 (16%)	21 (42%)	14 (28%)	4 (8%)

	running LED circuit.					
10	Errors in breadboard circuits were difficult to identify during the troubleshooting process.	5 (10%)	8 (16%)	23 (46%)	10 (20%)	4 (8%)

Note. *N* = Never; *R* = Rarely; *S* = Sometimes; *O* = Often; *VO* = Very Often. Values represent frequency (percentage).

Table III. Dominant Failure Factors in Breadboard Assembly

No	Failure Factor	Mean (M)	Response Tendency
1	Damaged components or overheated IC	3.54	Sometimes-Often
2	Incorrect polarity installation	3.30	Sometimes-Often
3	Incorrect wiring on breadboard	3.24	Sometimes-Often

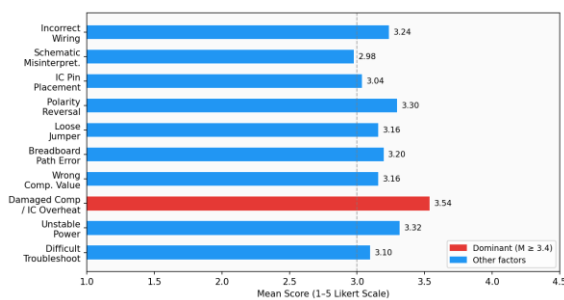


Fig. 5. Mean Score of Failure Factors in Breadboard Assembly

4.2 Failure Factors in PCB Assembly

Table IV presents student responses to PCB failure indicators. Broken PCB traces and open circuit defects produced the highest mean score among all PCB indicators ($M = 3.62$), followed by solder bridge defects and incorrect component placement, both at $M = 3.50$. PCB layout design errors recorded the lowest mean score among all PCB indicators ($M = 2.88$),

indicating that design-stage failures were less frequent than fabrication-stage failures. The dominant PCB failure factors are presented in Table V. The mean scores of all PCB failure factors are illustrated in Fig. 6.

Table IV. Students' Responses to the Failure Factors in PCB Assembly

N o	Statement	N	R	S	O	VO
1	Solder bridge defects caused circuit operational failure.	1 (2%)	6 (12%)	20 (40%)	13 (26%)	10 (20%)
2	Broken PCB traces (open circuits) or excessively thin traces caused the circuit to malfunction.	0 (0%)	6 (12%)	18 (36%)	15 (30%)	11 (22%)
3	Short circuits between adjacent PCB traces disrupted the operation of the running LED circuit.	1 (2%)	8 (16%)	19 (38%)	13 (26%)	9 (18%)
4	Errors in PCB layout design caused the circuit to malfunction.	7 (14%)	10 (20%)	20 (40%)	8 (16%)	5 (10%)
5	Errors during the PCB etching process	2 (4%)	7 (14%)	18 (36%)	14 (28%)	9 (18%)

	caused the circuit to malfunction.					
6	Poor soldering quality caused circuit failure due to unstable electrical connections.	2 (4%)	9 (18%)	20 (40%)	12 (24%)	7 (14%)
7	Incorrect component placement on the PCB caused operational problems in the circuit.	1 (2%)	6 (12%)	18 (36%)	17 (34%)	8 (16%)
8	Improper soldering of IC pins caused the running LED circuit to operate abnormally.	2 (4%)	12 (24%)	17 (34%)	13 (26%)	6 (12%)
9	Damage to PCB copper traces caused operational disruptions in the running LED circuit.	5 (10%)	6 (12%)	21 (42%)	12 (24%)	6 (12%)
10	Troubleshooting PCB circuits required repeated repair attempts during	2 (4%)	5 (10%)	20 (40%)	16 (32%)	7 (14%)

	practicum activities.					
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Note. *N = Never; R = Rarely; S = Sometimes; O = Often; VO = Very Often. Values represent frequency (percentage).*

Table V. Dominant Failure Factors in PCB Assembly

No	Failure Factor	Mean (M)	Response Tendency
1	Broken PCB traces / open circuit defects	3.62	Sometimes-Often
2	Solder bridge defects	3.50	Sometimes-Often
3	Incorrect component placement on PCB	3.50	Sometimes-Often

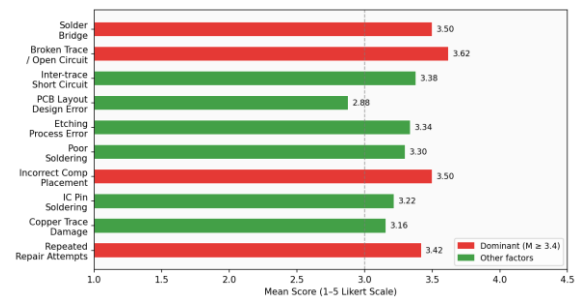


Fig. 6. Mean Score of Failure Factors in PCB Assembly

4.3 Comparison of Operational Failure Tendencies

Table VI presents the comparative analysis between breadboard and PCB assembly. PCB-related items consistently produced higher mean scores ($M = 3.10\text{--}3.18$) than breadboard-related items ($M = 2.86\text{--}2.92$), indicating that PCB assembly demonstrated a higher operational failure tendency overall. The comparison is summarized in Table VII. The comparison of operational failure tendencies between both assembly media is illustrated in Fig. 7.

Table VI. Students' Responses to the Comparison of Operational Failure Tendencies

No	Statement	N	R	S	O	VO
1	Breadboard assembly experienced operational problems during practicum activities.	4 (8%)	11 (22%)	22 (44%)	11 (22%)	2 (4%)
2	PCB assembly required more troubleshooting attempts during practicum activities.	1 (2%)	11 (22%)	21 (42%)	13 (26%)	4 (8%)
3	Errors in PCB circuits were difficult to identify during troubleshooting activities.	2 (4%)	10 (20%)	24 (48%)	9 (18%)	5 (10%)
4	Connection instability occurred during breadboard assembly activities.	6 (12%)	11 (22%)	18 (36%)	14 (28%)	1 (2%)
5	Errors during the PCB manufacturing process caused operational failure in the running LED circuit.	2 (4%)	11 (22%)	22 (44%)	6 (12%)	9 (18%)

Note. *N* = Never; *R* = Rarely; *S* = Sometimes; *O* = Often; *VO* = Very Often. Values represent frequency (percentage).

Table VII. Comparison of Operational Failure Tendencies Between Breadboard and PCB

No	Assembly Media	Mean Range	Failure Characteristic	Dominant Issues
1	Breadboard	2.86–2.92	Temporary connection instability	Loose jumper wires, unstable contact resistance
2	PCB	3.10–3.18	Permanent fabrication failure	Broken traces, solder bridge, etching defects

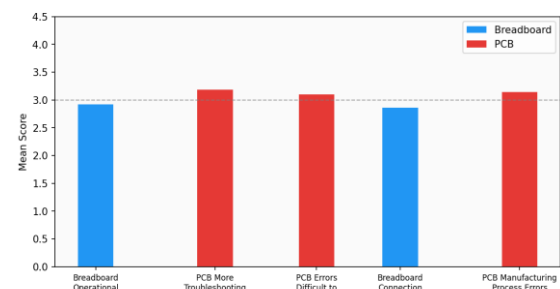


Fig. 7. Comparison of Operational Failure Tendencies Between Breadboard and PCB Assembly

The findings of this study confirmed all three research questions and produced several noteworthy patterns that extend beyond what prior literature on breadboard and PCB assembly failures would predict.

5.1 Dominant Failure in Breadboard Assembly

The dominant failure factor in breadboard assembly was damaged components and IC overheating ($M = 3.54$), not wiring error as might be expected from prior literature. This result was particularly significant because it indicated that the primary failure mode in

breadboard-based running LED circuit assembly was not misconnection but rather power mishandling — specifically, reversed supply connections or undetected short circuit conditions that sustained thermal stress on the NE555 timer and CD4017 counter beyond their rated operating limits. Previous studies on LED-based circuit failure have consistently identified damaged drive circuit components, including resistors and integrated circuits, as primary failure sources rather than the LED elements themselves [6], [7]. The present findings extend this pattern to the educational assembly context, where student-level power management errors appear to be the critical failure mechanism rather than layout misinterpretation.

This result also aligns with Bianchi et al. [16], who observed that intermittent faults caused by unstable breadboard connections can expose components to repeated electrical stress, increasing cumulative thermal damage over multiple testing cycles. Incorrect polarity installation ranked second ($M = 3.30$), which is directly related to the overheating finding. Polarity reversal in a running LED circuit places both the LEDs and the driving ICs under reverse bias conditions, which can cause immediate component failure if not detected quickly. The consistent co-occurrence of polarity errors and component overheating suggests these two failure modes are not independent — polarity mishandling is likely a direct precursor to IC thermal damage in many cases. Incorrect wiring ranked third ($M = 3.24$), consistent with findings from Alessandrini [1] and Alessandrini [17], both of whom documented wiring and connection mapping errors as recurring challenges in breadboard-based electronics prototyping among undergraduate students.

5.2 Dominant Failure in PCB Assembly

Broken PCB traces and open circuit defects emerged as the dominant failure source in PCB

assembly ($M = 3.62$), which was also the highest mean score recorded across all failure indicators in both media. This finding directly implicates the ferric chloride etching process as the most critical failure point in student-level PCB production. Atta [11] demonstrated that insufficient agitation, incorrect FeCl_3 concentration, and inadequate immersion time collectively produce over-etching that damages or completely removes copper traces, creating open circuit conditions that permanently disrupt signal flow. In the running LED circuit specifically, where the CD4017 counter must maintain isolated output lines to individual LED channels, a single broken trace can cause one or more LEDs to remain permanently off regardless of circuit power status — a failure mode that is both difficult to diagnose and irreparable without physical trace reconstruction.

A particularly noteworthy finding was that PCB layout design errors recorded the lowest mean score among all PCB indicators ($M = 2.88$), well below the fabrication-stage failures. This gap between design comprehension and physical execution indicated that students generally understood how to produce a correct PCB layout but consistently encountered difficulty translating that design into a reliable physical board during etching and soldering. This pattern has direct implications for practicum instruction — it suggests that additional guidance should be allocated to etching process control and soldering technique rather than to layout design theory, which students appear to have adequately internalized. The types of conductive defects documented in this study, including broken traces, solder bridges, and inter-trace short circuits, are consistent with PCB defect categories identified in previous literature on PCB quality inspection [12], [13]. The hazardous chemical waste generated by the ferric chloride etching process has also been recognized as an environmental concern in educational PCB fabrication

contexts. Ariyanto [21] demonstrated that CNC-based PCB manufacturing produces only non-hazardous paper dust and copper flake waste, offering a safer alternative to conventional wet etching methods in vocational laboratory settings.

5.3 Comparison: Breadboard vs PCB

The comparative analysis revealed that PCB assembly demonstrated consistently higher operational failure complexity than breadboard assembly, with mean scores ranging from 3.10 to 3.18 compared to 2.86 to 2.92 for breadboard items. This finding challenges the common assumption in introductory electronics education that breadboard is inherently the more error-prone medium. While breadboard assembly did produce connection instability ($M = 2.86$), these failures were reversible — a loose jumper can be repositioned and a wiring error corrected without any permanent consequence to the board. PCB failures, by contrast, involved permanent conductive path damage requiring repeated repair attempts and considerably more troubleshooting effort, as reflected in the higher comparative mean scores. This distinction between reversible and irreversible failure modes represents a meaningful practical difference in how each medium challenges students during practicum activities.

The dominant response category across both media remained Sometimes rather than Often or Very Often, indicating that failure occurrence was inconsistent across the student population rather than systematic. This pattern suggests that individual differences in assembly skill, procedural attention, and prior practical experience played a significant role in determining circuit reliability outcomes — a finding consistent with Van De Bogart et al. [9], who observed that students with more structured diagnostic approaches demonstrated considerably better fault identification and correction performance. Dounas-Frazer and

Lewandowski [2] similarly noted that troubleshooting effectiveness in electronics laboratory settings is strongly tied to the quality of explicit instruction students receive rather than intuitive ability alone. The variability in failure frequency observed in this study further supports the argument that structured troubleshooting instruction — covering both breadboard connection verification and PCB fabrication process control — could meaningfully reduce assembly failure rates in vocational electronics laboratory education.

5. KESIMPULAN

This study identified the dominant failure factors in running LED circuit assembly using breadboard and PCB media among 50 vocational electronics engineering students at Sriwijaya State Polytechnic. In breadboard assembly, damaged components and IC overheating was the dominant failure factor ($M = 3.54$), followed by incorrect polarity installation ($M = 3.30$) and incorrect wiring ($M = 3.24$). In PCB assembly, broken copper traces and open circuit defects dominated ($M = 3.62$), followed by solder bridge defects and incorrect component placement ($M = 3.50$). Comparative analysis confirmed that PCB assembly demonstrated a higher overall operational failure tendency than breadboard assembly, with mean scores of 3.10–3.18 versus 2.86–2.92 respectively.

These findings suggest that breadboard failures are predominantly reversible and rooted in power mishandling rather than wiring errors, while PCB failures are largely permanent and driven by fabrication process execution. Practicum instruction should therefore prioritize power supply verification procedures for breadboard assembly, and etching process control alongside soldering technique for PCB assembly, rather than focusing instructional time on layout design theory which students appear to have adequately internalized.

This study is limited to one institution and relies on self-reported survey data, which may affect generalizability. Future research could apply direct observational methods during practicum activities and extend the investigation to more complex circuit modules across multiple vocational institutions to further validate these findings.

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REFERENCES

- [1] A. Alessandrini, "A study of students engaged in electronic circuit wiring in an undergraduate course," *J. Sci. Educ. Technol.*, vol. 32, no. 1, pp. 78–95, Feb. 2023, doi: 10.1007/s10956-022-09994-9.
- [2] D. R. Dounas-Frazer and H. J. Lewandowski, "Electronics lab instructors' approaches to troubleshooting instruction," *Phys. Rev. Phys. Educ. Res.*, vol. 13, no. 1, p. 010102, 2017, doi: 10.1103/PhysRevPhysEducRes.13.010102.
- [3] K. A. Pepler, R. M. Sedas, and N. Thompson, "Paper circuits vs. breadboards: Materializing learners' powerful ideas around circuitry and layout design," *J. Sci. Educ. Technol.*, vol. 32, no. 4, pp. 469–492, 2023, doi: 10.1007/s10956-023-10029-0.
- [4] Texas Instruments, *NE555 Precision Timers Datasheet*. Dallas, TX, USA: Texas Instruments, 2023. [Online]. Available: <https://www.ti.com/lit/ds/symlink/ne555.pdf>
- [5] Texas Instruments, *CD4017B CMOS Decade Counter/Divider with 10 Decoded Outputs Datasheet*. Dallas, TX, USA: Texas Instruments, 2023. [Online]. Available: <https://www.ti.com/lit/ds/symlink/cd4017b.pdf>
- [6] W. Zhong and T. Walther, "Failure analysis of some commercial spotlights based on light emitting diodes," *Electronics*, vol. 11, no. 1, p. 48, 2022, doi: 10.3390/electronics11010048.
- [7] H. Yao, Y. Li, Y. Zhang *et al.*, "Failure mechanism and analysis diagnosis of LED," *MAPAN*, vol. 37, no. 1, pp. 195–206, 2022, doi: 10.1007/s12647-021-00518-1.
- [8] Z. Chen, Q. Zhang, K. Wang, X. Luo, and S. Liu, "Reliability test and failure analysis of high power LED packages," *J. Semicond.*, vol. 32, no. 1, p. 014007, 2011, doi: 10.1088/1674-4926/32/1/014007.
- [9] K. L. Van De Bogart, D. R. Dounas-Frazer, H. J. Lewandowski, and M. R. Stetzer, "Investigating the role of socially mediated metacognition during collaborative troubleshooting of electric circuits," *Phys. Rev. Phys. Educ. Res.*, vol. 13, no. 2, p. 020116, 2017, doi: 10.1103/PhysRevPhysEducRes.13.020116.
- [10] H. B. Park, S. K. Hong, and R. Tomasek, "Reducing PCB solder process defects and improving PCB solder joint reliability through computer simulation," in *Proc. 12th Annu. IEEE Semicond. Thermal Meas. Manage. Symp.*, Austin, TX, USA, Mar. 1996, doi: 10.1109/STHERM.1996.545101.
- [11] R. M. Atta, "Effect of applying air pressure during wet etching of micro copper PCB tracks with ferric chloride," *Int. J. Mater. Res.*, vol. 113, no. 9, pp. 795–808, 2022, doi: 10.1515/ijmr-2021-8343.
- [12] Q. Ling and N. A. M. Isa, "Printed circuit board defect detection methods based on image processing, machine learning and deep learning: A survey," *IEEE Access*, vol. 11, pp. 15921–15944, 2023, doi: 10.1109/ACCESS.2023.3245093.
- [13] X. Chen, Y. Wu, X. He, and W. Ming, "A comprehensive review of deep learning-based PCB defect detection," *IEEE Access*, vol. 11, pp. 139017–139038, 2023, doi: 10.1109/ACCESS.2023.3339561.
- [14] K. P. Anoop, N. S. Sarath, and V. V. Sasi Kumar, "A review of PCB defect detection using image processing," *Int. J. Eng. Innovative Technol.*, vol. 4, no. 11, pp. 188–192, 2015. [Online]. Available: <https://www.scribd.com/document/746911971/journal-pcb>
- [15] A. Bhattacharya and S. G. Cloutier, "End-to-end deep learning framework for printed circuit board manufacturing defect classification," *Sci. Rep.*, vol. 12, p. 12559, Jul. 2022, doi: 10.1038/s41598-022-16302-3.
- [16] A. Bianchi, K. J. Moon, A. Dementyev, and S. Je, "BlinkBoard: Guiding and monitoring circuit assembly for synchronous and remote physical computing education," *HardwareX*, vol. 17, p. e00511, 2024, doi: 10.1016/j.ohx.2024.e00511.
- [17] A. Alessandrini, "How an undergraduate group of design students solved wiring errors during the prototyping of an interactive artifact," in *Proc. Eur. Conf. Cogn. Ergon. (ECCE)*,

- Kaiserslautern, Germany, Oct. 2022, doi: 10.1145/3552327.3552345.
- [18] J. W. Creswell, *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 4th ed. Thousand Oaks, CA, USA: SAGE Publications, 2014.
- [19] L. Cohen, L. Manion, and K. Morrison, *Research Methods in Education*, 8th ed. London, U.K.: Routledge, 2018.
- [20] I. Etikan, S. A. Musa, and R. S. Alkassim, "Comparison of convenience sampling and purposive sampling," *Am. J. Theor. Appl. Stat.*, vol. 5, no. 1, pp. 1–4, 2016, doi: 10.11648/j.ajtas.20160501.11.
- [21] D. Ariyanto, "Penggunaan Mesin CNC untuk Mengatasi Limbah B3 (Bahan Beracun dan Berbahaya) dalam Proses Pembuatan PCB," *J. Inform. dan Tek. Elektro Terap.*, vol. 13, no. 3, 2025, doi: 10.23960/jitet.v13i3.6767.