International Journal of Engineering Trends and Technology
ISSN: 2231-5381/ https://doi.org/10.14445/22315381/IJETT-V74I5P111

Volume 74 Issue 5, 169-184, May 2026

Original Article

Innovation in the Teaching of Analog Electronics: Laboratory Guides for Autonomous Learning

Gorostiaga Machicao-Victor Hugo[1], Palma Reyes- Alejandro Dumas[2], Urbano Alva- Jorge Luis[3], Cuba Vargas- Karen Esteincin[4], Palomino Monteza -Vanessa Yaniz[5]

[1,2,3,4]*Servicio Nacional de Adiestramiento en Trabajo Industrial (SENATI), Lima, Perú.*
[5]*Directorate of Research, Centro de Altos Estudios Nacionales, Lima, Perú.*

[4]*Corresponding Author : ecuba@senati.edu.pe*

Received: 18 October 2025 Revised: 17 February 2026 Accepted: 03 March 2026 Published: 30 May 2026

Abstract *- The teaching of analog electronics faces the challenge of integrating theory with practice in educational environments increasingly influenced by digitalization and the changes brought about by the COVID-19 pandemic, and in this context, self-directed learning has become a key competency in the training of professionals capable of meeting the demands of Industry 4.0. The aim of this study was to design and propose laboratory guides that strengthen students' autonomous learning in an advanced-level analog electronics course and the proposed framework is organized into three stages: preliminary research and circuit simulation, experimental development in the laboratory, and analysis of results through questionnaires and conclusions, and additionally, it incorporates assessment tools such as observation checklists with specific criteria to evaluate technical, procedural, and socio-emotional competencies which are proposed as an innovative didactic resource that improves coherence between curricular objectives and practical experiences, promotes student motivation, and supports the progressive acquisition of critical skills for professional performance and the expected outcomes point to greater autonomy in learning, consistency in the implementation of laboratory practices, and the generation of useful indicators for the continuous improvement of training programs in technological institutions*.

Keywords *- Laboratory Practices, Analog Electronics, Self-Learning, Educational Innovation, and Technological Education.*

1. Introduction

The learning of analog electronics constitutes a fundamental pillar in the training of engineering and technology students, as its principles support applications in telecommunications, control, instrumentation, power electronics, and mechatronic systems; however, persistent difficulties remain in achieving a coherent integration between theoretical content and experimental practice, which limits the meaningful development of technical and procedural competencies, and this problem has become more evident in recent years due to shifts in educational models and the disruption caused by the COVID-19 pandemic, which forced institutions to modify laboratory dynamics and exposed structural weaknesses in practical training [1, 2].

Although previous studies have demonstrated that hands-on experiences enhance motivation, knowledge retention, and the acquisition of cognitive and socio-emotional skills [3], recent research further confirms that the effectiveness of laboratory-based learning depends strongly on the degree of structure, guidance, and alignment between objectives, activities, and assessment instruments [13, 14]. In contemporary engineering education, the traditional laboratory model based on rigid schedules, shared equipment, and instructor-centered demonstrations has been progressively complemented by innovative approaches such as portable laboratories, simulation-supported experimentation, and hybrid physical-virtual environments, which aim to foster autonomy, flexibility, and deeper conceptual understanding [15, 16] an studies on lab-in-a-box and mobile laboratory platforms demonstrate that when students have permanent access to instrumentation and guided experimental tasks, they develop greater independence, confidence, and problem-solving ability in analog electronics courses [17, 18]. Likewise, research on simulation-supported laboratory instruction shows that combining circuit simulators with physical experimentation enables students to verify theoretical models, explore parameter variations, and reduce dependence on instructor intervention, thereby strengthening self-directed learning processes [14, 19].

Despite these advances, a clear research gap persists regarding the design, implementation, and empirical validation of standardized laboratory guides specifically adapted to technological higher education in analog electronics. Many existing studies emphasize active learning, project-based learning, or digital tools, but they rarely provide comprehensive and structured laboratory materials that integrate theoretical foundations, simulation, step-by-step experimental procedures, and systematic assessment of learning outcomes [13, 20] and this limitation leads to heterogeneity in laboratory practices, instructor-dependent methodologies, and inconsistent evaluation criteria, which in turn weakens the reliability and comparability of learning outcomes across different cohorts and institutions [15, 21].

Recent research on project-based learning in analog electronics has shown that when laboratory activities are embedded in structured design-oriented tasks, students significantly improve their ability to select components, analyze circuits, and connect theory with real-world applications [22, 23] and similarly, flipped-classroom and blended-learning models in engineering education have demonstrated positive effects on students' self-directed learning, technological acceptance, and conceptual understanding, particularly when pre-class preparation is combined with guided in-class experimentation [24, 25]. In addition, comparative studies of physical and virtual laboratories confirm that learning gains are maximized when both modalities are integrated within a coherent pedagogical framework supported by well-designed instructional materials [23].

Given this gap, it becomes necessary to develop didactic resources that ensure coherence between curricular objectives, workplace demands, and students' autonomous learning needs and laboratory guides structured with theoretical foundations, detailed experimental procedures, simulation activities, pre- and post-activity questionnaires, and explicit evaluation criteria represent a practical and pedagogically robust strategy to strengthen the teaching–learning process in analog electronics, particularly in technological institutes that require tools to standardize laboratory execution and support both teachers and learners [13, 18, 22], unlike previous studies that focus primarily on methodological recommendations, isolated digital tools, or general pedagogical principles, the present work contributes by offering a concrete, structured, and empirically validated set of laboratory practice guides specifically designed for a Higher Technological Institute, integrating physical experimentation, simulation, and competency-based assessment into a unified instructional model.

The purpose of this article is therefore to present the design, structure, and pedagogical rationale of these laboratory guides oriented toward autonomous learning, emphasizing their potential to improve the development of technical, procedural, and socio-emotional competencies in students, by addressing a documented gap in practical training resources and complementing existing international literature with an operational and adaptable proposal, this study seeks to provide empirical support and pedagogical alternatives that strengthen the teaching of analog electronics in higher technological education [1, 3, 13, 23].

2. Literature Review

The implementation of active and autonomous learning strategies in engineering education has been widely documented in the international literature, and Lima et al. highlight that teacher training and pedagogical innovation are decisive factors for the effective adoption of active learning methodologies in engineering programs, showing significant improvements in student engagement and learning outcomes [4]. Hernández et al. likewise emphasize that rigorous scientific structuring of educational research is essential to ensure coherence between theory, methodology, and empirical analysis [5].

Beyond these general frameworks, recent studies in analog electronics education have increasingly focused on the role of structured laboratory environments in fostering meaningful learning. Mantri et al. demonstrated that a Project-Based Learning (PBL) approach in analog electronics significantly improves students' conceptual understanding and design skills when laboratory activities are guided by clearly defined objectives and assessment criteria [22].

Similar results were reported by Tokatlidis et al. and Devika and Sanchez, who showed that structured and project-oriented laboratory courses lead to higher levels of engagement, problem-solving ability, and practical competence in analog circuit design [21, 23].

At the same time, the emergence of portable and mobile laboratory platforms has transformed traditional laboratory pedagogy. Kester and Connor et al. reported that devices such as portable oscilloscopes, function generators, and multifunctional learning modules allow students to perform authentic analog electronics experiments outside conventional laboratories, thereby promoting continuous and autonomous practice [16, 18]. These findings are supported by Ferri et al., who demonstrated that hands-on, in-class laboratories supported by portable instrumentation significantly improve learning outcomes in large enrollment circuits courses [14].

Digital technologies have further expanded the possibilities for self-directed learning in electronics. Baltzis showed that the integration of circuit simulation tools with laboratory experiments helps students become more independent in circuit analysis and troubleshooting [19], while Shu-Yan et al. demonstrated that web-based circuit simulators promote creative and independent learning by shifting laboratory activities from a teacher-centered to a learner-centered paradigm [20]. Moreover, comparative studies by Tokatlidis et al. confirm that combining physical and virtual laboratories enhances both conceptual understanding and measurement skills in electronic circuits learning [23]. Finally, pedagogical models such as the flipped classroom have been shown to reinforce autonomous learning in engineering students. Zainuddin et al. and Zhang et al. found that flipped learning environments significantly improve students' self-directed learning, confidence, and technological acceptance when pre-class preparation is linked to guided in-class problem solving and experimentation [24, 25].

Together, these studies provide strong empirical evidence that structured, technology-supported, and learner-centered laboratory environments are essential for developing autonomy and competence in analog electronics education.

2.1. Population and Context

The proposal was aimed at students of the Mechatronic Engineering program (formerly Electronic Engineering) at the higher technological level, who develop technical, procedural, and socio-emotional competencies through the dual training methodology (institute–industry). The contents of the guides were based on the official syllabus of the Analog Electronics course, which includes eight main tasks distributed over 16 academic weeks.

2.2. Materials and Resources

For the preparation of the guides, the following were used:

Table 1. Materials and resources used in the proposed laboratory guides

Category	Description
Laboratory equipment	- Adjustable power supply (0–30 VDC) - Digital multimeter - Oscilloscope - Function generator - Protoboard
Electronic components	- Precision and variable resistors - Rectifier diodes and LED emitters - BJT, FET, and MOSFET transistors - Operational amplifiers - Voltage regulators - Optocouplers and phototransistors - IGBT, UJT, SCR, and TRIAC
Simulation software	- Tinker CAD - Proteus (for modeling and analyzing electronic circuits)
Digital resources	- Institutional templates and formats - QR codes for access to guides - Institutional cloud repository
Supporting materials	- Practical manuals - Specialized bibliography on analog electronics – Institutional regulations on laboratory practices

2.3. Procedure

Table 2. Guide the development process in three phases

Category	Description
Curriculum and regulatory analysis	Review of course objectives and institutional regulations on laboratory practices, as well as similar experiences at national and international institutions.
Structural design	A standard structure was defined, consisting of ten sections: title, objectives, competencies, theoretical basis, equipment and materials, experimental procedure, preliminary questionnaire, final questionnaire, conclusions, and bibliographical references.
Preliminary validation	The proposal was reviewed by specialist teachers in the field, who assessed its pedagogical relevance, consistency with learning objectives, and feasibility of application in the laboratory.

2.4. Application and Evaluation Strategy

Table 3. Guide the development process in three phases

Category	Description
Prior research and simulation	Focused on developing self-learning
Experimental laboratory practice	Aimed at consolidating technical and procedural skills through the handling of instruments and circuits.
Analysis and final reflection	Based on questionnaires and conclusions that encourage metacognition and critical thinking skills in students.

For the evaluation, an observation guide was designed with twenty aspects and six assessment criteria, which made it possible to measure the students' progress in each phase of the process.

2.5. Instrument Validation and Reliability

The reliability and validity of the assessment instruments were verified to ensure methodological rigor, the Likert-scale perception survey showed high internal consistency, with a Cronbach's alpha coefficient of 0.87 and its performance was reviewed by three subject-matter experts, who evaluated the clarity, relevance, and alignment of each indicator with course competencies, and inter-rater reliability testing during a pilot application produced a Cohen's kappa value of 0.82, confirming consistent scoring among evaluators and construct validity was supported by a positive correlation (r = 0.71) between checklist scores and final test performance, indicating that the instruments measured related dimensions of competency development.

4. Results and Discussion

4.1. Methodological Design of the Proposal

Based on the review of the theoretical framework and current institutional regulations, eight laboratory practice guides were developed for the Analog Electronics course and the design considered the following key aspects: First, the structure of the guides was organized into ten fundamental sections, distributed across three main parts, in accordance with the institution's rules and regulations and each guide was developed with objectives and practical content directly linked to the eight tasks of the Professional Training Program, ensuring curricular alignment. Second, it was verified that all proposed electronic circuits met the course objectives, ensuring coherence between theory and practice. Likewise, tables and grid spaces were included for students to record experimental data and graphs of the signals obtained during the development of the experiment. As an added value, Graphic Identifiers (QR codes) were assigned to facilitate digital access to each guide and their online maintenance, promoting the integration of physical and virtual resources. An observation guide was designed as an evaluation instrument, consisting of twenty aspects and six assessment criteria, which allows for monitoring students' performance and progress. To strengthen the empirical foundation of the study, a Quasi-Experimental pretest and posttest design was implemented to evaluate the pedagogical impact of the structured laboratory guides on students enrolled in the Analog Electronics course at a Higher Technological Institute during the 2024-II academic period. The data collection incorporated four complementary instruments: (a) a diagnostic knowledge test; (b) performance checklists applied during laboratory sessions to assess procedural competencies; (c) Likert-type surveys evaluating autonomy, motivation, and perceived usefulness of the guides; and (d) a final achievement test aligned with course competencies and the internal consistency of the survey instrument was verified using Cronbach's alpha and statistical comparisons between pre- and posttest results were conducted using Student's t-test with effect size calculations and this expanded methodological structure allows for a more rigorous demonstration of the pedagogical effectiveness of the proposed guides.

Table 4. Action Plan for the Design of the Laboratory Practice Guide Structure for the Analog Electronics Course

Specific objective	Activities / Tasks	Time (days)	Resources	Indicator
Develop laboratory practice guides to improve students' self-learning and align them with the objectives of the analog electronics course at the Higher Technological Institute.	Conduct an analysis of the educational objectives of the analog electronics course.	12	Final structure of the guide	List of objectives for each guide (8)
			Curriculum and course content	
	Research and review similar laboratory practice guidelines to define content.	20	Analog electronics books and/or manuals	List of contents for each guide
			Guides from other institutions and the operational area guide	
	Develop the general structure of the laboratory practice guides.	10	List of contents for each guide	Structure of each guide (8) with objectives and contents
	Develop practical circuits that are aligned with the course objectives.	15	Analog electronics books and/or manuals	List of electronic circuits for the 8 guides
			Electronic circuit drawing and simulation program	
			Guide structure with objectives and contents	
	Design formats and templates for presenting information in the guide.	10	Guide structure with objectives and contents	Formats for the 8 practical laboratory guides
			List of electronic circuits for the 8 guides	
	Conduct a final review of the practical laboratory guidelines.	8	Formats for the 8 practical laboratory guides	Final formats for the 8 practical laboratory guides

4.2. Design and Validation of the Guides

Eight laboratory practice guides were developed, aligned with the tasks of the analog electronics course. Each guide included: objectives, competencies, theoretical foundations, materials, procedures, questionnaires, and evaluation criteria. QR codes were integrated for digital access and cloud storage. Below, we present laboratory guide No. 02:

Table 5. Action plan for developing practical laboratory guidelines to improve student self-learning

Specific objective	Activities / Tasks	Time (days)	Resources	Indicator
Evaluate the use of laboratory practice guides to verify that they meet the objectives of the Analog Electronics course through an observation guide.	Establish clear and specific criteria for evaluating the laboratory practices guide	2	Institutional standard for practical assessment (ACAD-P-37)	Evaluation criteria are defined based on existing criteria
	Design an observation guide that serves as a tool for evaluating the laboratory practices guide.	7	Final formats for the 8 practical laboratory guides	Initial observation guide
			Guides for observing similar laboratory practices	
			Criteria defined based on existing criteria	
	Organize the observation guide based on the designed guide.	2	Final structure of the guide	Observation guide organized into three sections
			Initial observation guide	
	Define the values that will be collected when applying the observation guide	2	Observation guide organized into three sections	Values to be obtained in each section of the observation guide
	Define the analysis of data and results that will be obtained when applying it	2	Values to be obtained in each section of the observation guide	Design of the modular structure of the guide
	Review and approve the final observation guide	1	Design of the modular structure of the guide	Final observation guide

Table 6. Action plan for evaluating the use of laboratory practice guidelines

Specific objective	Activities	Time (days)	Resources	Indicator
Design the structure of the laboratory practice guide for the analog electronics course, taking into account the standards of the Higher Technological Institute.	Obtain information on the rules and regulations of the Higher Institute	3	Institutional policies, rules, and formats	List of policies and rules to follow
	Analyze the educational objectives of the analog electronics course.	1	Curriculum and course content	Identification within the course content
	Define the structure of laboratory practices in parts or sections.	4	Course workshop session plan format	3-section structure format
			Guidelines from other institutions and operational area guidelines	
	Design the overall structure of the laboratory practice guide	3	Section structure format	Model structure of the guide
			Similar structures for engineering courses	
	Identify and select resources to improve the structure of the guide	2	QR code generation programs, Microsoft tools	Online storage and QR code
	Evaluate the designed structure by the course instructors	2	Guidelines from other institutions and operational area guidelines	Final structure of the guide
			Course workshop session plan format	
			Model structure of the guide	

Institution Logo	**LABORATORY PRACTICE GUIDE No. 02** ANALOG ELECTRONICS	

Section 1	
Title	Single-phase half-wave and full-wave rectifier
Objective	Assemble and verify the operation of half-wave and full-wave rectifier circuits to convert alternating voltage into pulsating direct current using rectifier diodes.
Competencies to be developed	
Technical	Identifies, measures, analyzes, and compares data from a single-phase half-wave and full-wave rectifier, according to theory, practice developed, and manufacturer specifications
Methodical	Plans a sequence of activities based on the objective to be achieved in the experiment. Program-specific tasks are assigned to work group members based on the time required for the experiment.
Personal-Social	Works in a team, maintaining cordiality and respect with all members. Listens and contributes opinions in the work group, based on the objective to be achieved. Responsibly fulfills the assigned task within established deadlines.
Theoretical Foundation	

Rectifier Circuits

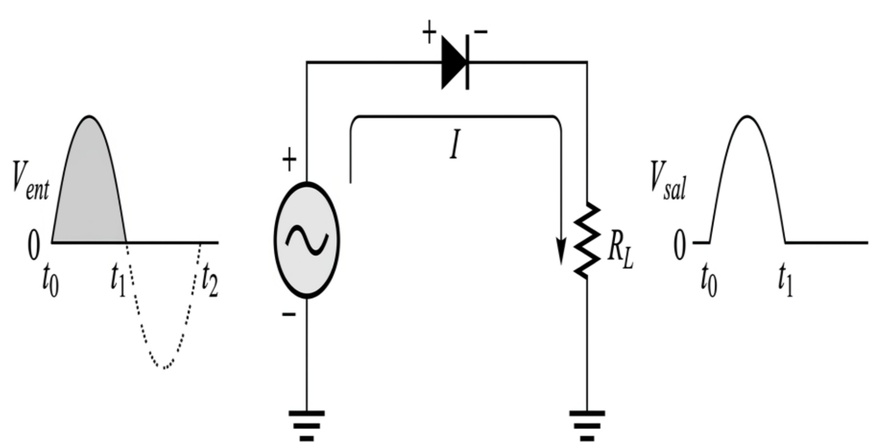
A rectifier circuit converts an alternating voltage into pulsating direct voltage and uses diodes, due to their ability to conduct current in one direction and block it in the other (Floyd, 2008)

Half-Wave Rectifier

A diode is connected to a load resistor and an alternating current source to create an RL half-wave rectifier. When the positive half-cycle of the sinusoidal input voltage (Vin) is delivered, the diode conducts current through the RL resistor, producing an output voltage across it, due to being forward biased Figure 1.

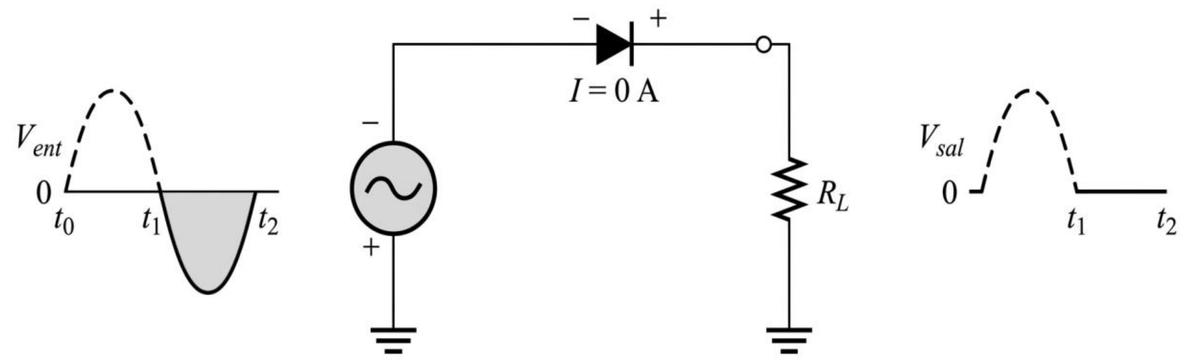
For the second half-cycle of the input signal (Vin), which is negative, the diode is reverse-biased, does not conduct current through the load resistor, so its voltage is zero Figure 2.

The result at the output is that the waves passing through the load will be those of the positive half-cycle, since they do not change polarity; it is a continuous pulsating DC voltage with a frequency of 60 Hz Figure 3 (Floyd, 2008).



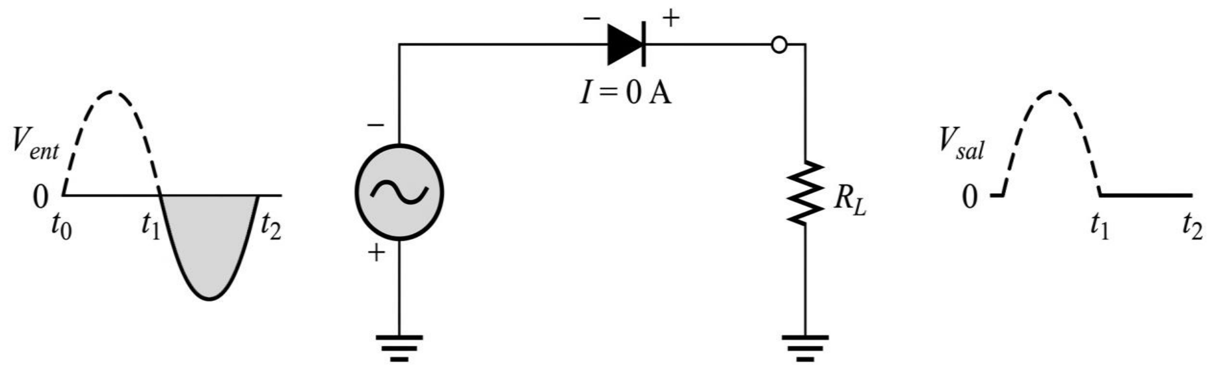
Source: (Floyd, 2008)

Fig. 1 Forward bias



Source: (Floyd, 2008)

Fig. 2 Reverse bias

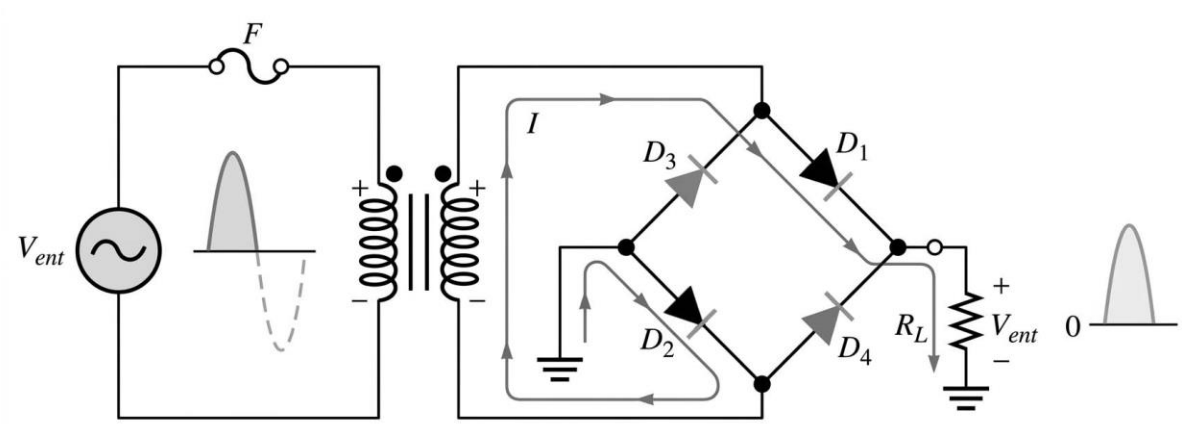


Source: (Floyd, 2008)

Fig. 3 Rectified output signal

Full-Wave Rectifier

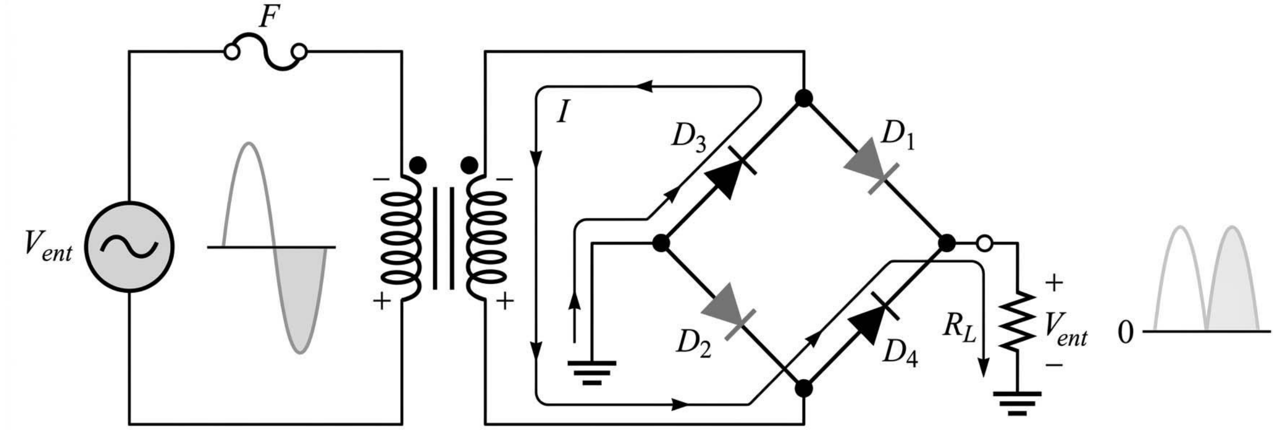
The rectifier bridge uses four diodes connected as shown in Figure 4(a). When the input cycle is positive, as in section (a), and diodes D1 and D2 are forward biased and conduct current in the direction shown. A voltage is generated across RL similar to the positive input half-wave. At this time, semiconductor devices D3 and D4 are reverse-biased and do not conduct (Floyd, 2008)



Source: (Floyd, 2008)

Fig. 4(a) Operation of diodes D1 and D2

When the input half-cycle is negative, as shown in Figure 4(b), diodes D3 and D4 are forward-biased and conduct current in the same direction through RL, as shown in the positive half-cycle. In the negative half-period, D1 and D2 are reverse-biased. As a result of this procedure, a full-wave rectified output voltage appears across RL (Floyd, 2008).



Fuente : (Floyd, 2008)

Fig. 4(b) Partial operation of diodes D3 and D4

Preliminary Report Questionnaire

1. Regarding the concept of half-wave rectification given in Thomas Floyd's theoretical foundation, what do Robert Boylestad and Albert Malvino define?
2. What parameters are important in half-wave rectification?
3. If the diode short-circuits, what voltage would drop across resistor R_L?
4. What are the technical specifications of the 1N4007 diode?
5. Why is the peak inverse voltage important in a diode?
6. What restrictions does the reverse recovery time establish in a diode?
7. Calculate the peak value of the output voltage for the half-wave rectifier circuit.
8. Calculate the DC output voltage value in the half-wave rectifier.
9. Simulate the half-wave rectifier following steps 1 through 11, using available software, and obtain the waveform at the circuit output.
10. Briefly describe the demonstration performed through simulation, explaining the results of Figure 5.
11. Calculate the peak value of the output voltage for the full-wave rectifier bridge circuit.
12. Calculate the DC output voltage value in the full-wave rectifier bridge circuit.
13. Simulate the full-wave rectifier bridge circuit following steps 12 through 17, using available software, and obtain the waveform at the circuit output.
14. Briefly describe the demonstration performed through simulation, explaining the results of Figure 6.

Equipment and materials

- 01 full-wave step-down transformer: 220V a 12V - 0V - 12V
- 04 diodes 1N4007 or similar.
- 01 resistor 10 KΩ ½ W
- 01 resistor 100 KΩ ½ W
- 01 dual-trace oscilloscope 60/100 MHz

Section 2

Procedure

Half-wave rectifier

Implement the circuit shown in Figure 5:

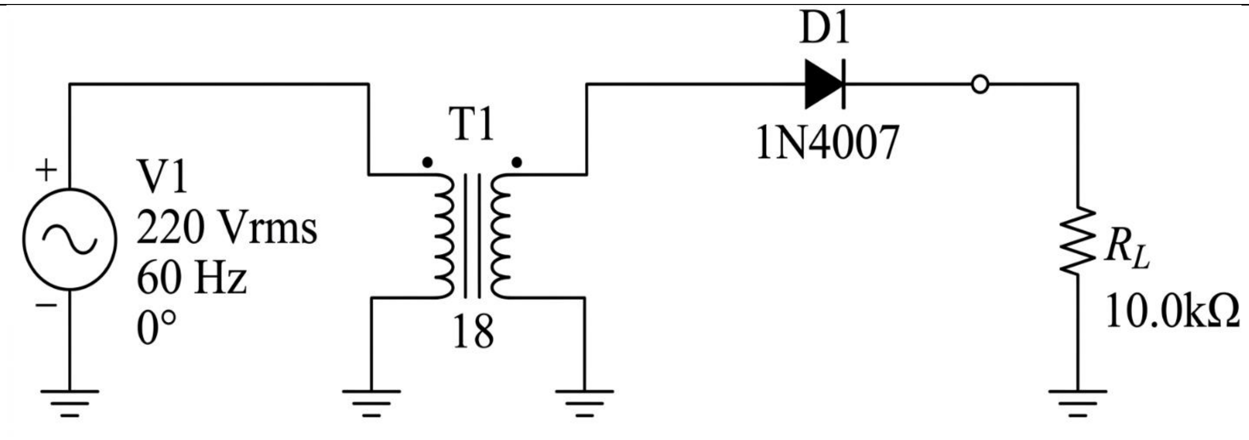


Fig. 5 Half-wave rectifier circuit

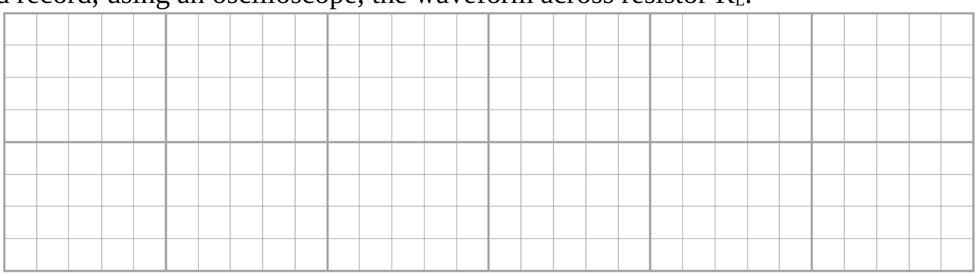
Measure the AC voltage at the transformer secondary.

Measure, with a voltmeter, the DC voltage across resistor R_L

Measure, with a voltmeter, the DC voltage across the diode.

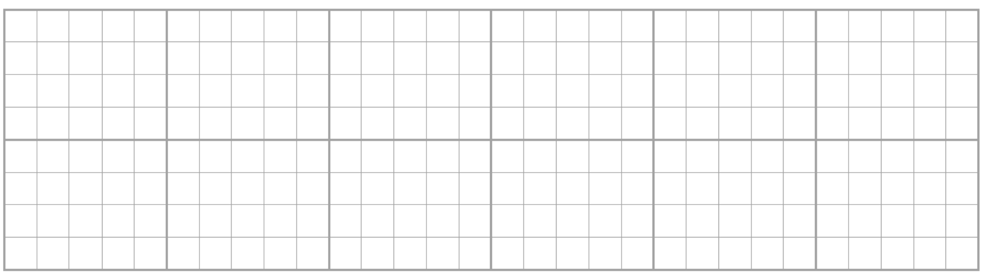
Voltages to measure	Measured values	Units
Secondary voltage (AC)		
Load resistance voltage (DC)		
Diode voltage (DC)		

Measure and record, using an oscilloscope, the waveform across resistor R_L.



Draw the recorded image here.

Measure and record, using an oscilloscope, the waveform across the diode. Make sure to connect the probe to the diode.



Draw the obtained image here.

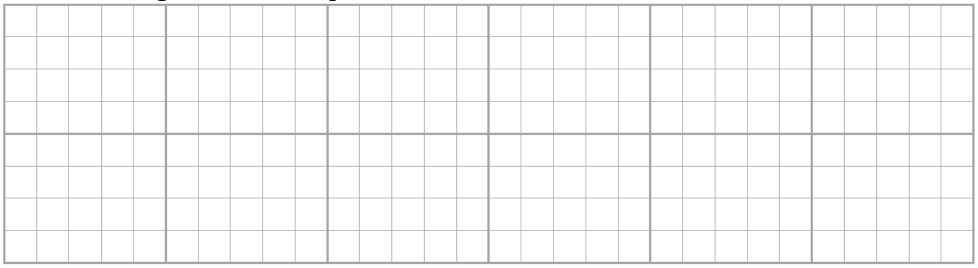
Remove power, reverse the diode, and restore power.

Measure, with a voltmeter, the DC voltage across resistor R_L.

Measure, with a voltmeter, the DC voltage across the diode.

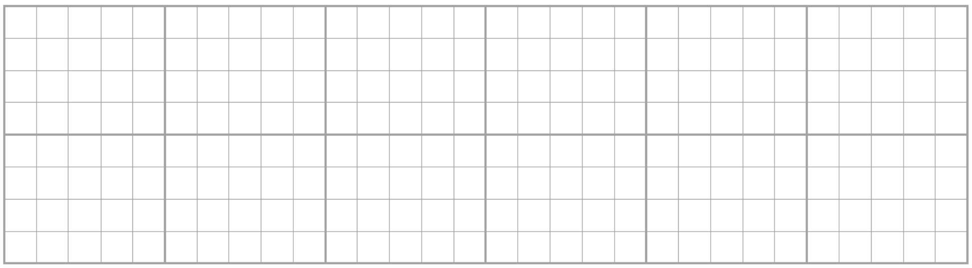
Voltages to measure	Measured values	Units
Load resistance voltage (DC)		
Diode voltage (DC)		

Measure and record, using an oscilloscope, the waveform across resistor R_L.



Draw the obtained image here.

Measure and record, using an oscilloscope, the waveform across the diode. Make sure to connect the probe to the diode.



Draw the obtained image.

Full-wave rectifier

Implement the circuit shown in Figure 6:

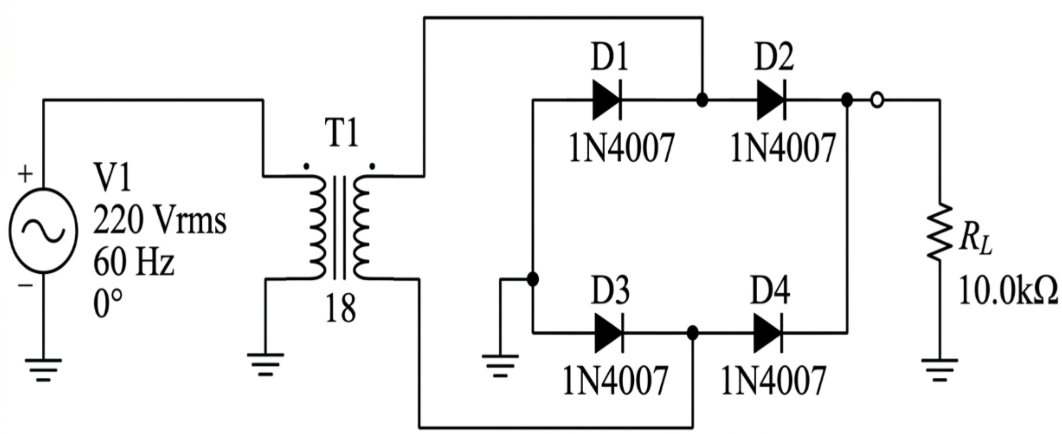


Fig. 6 Full-wave rectifier bridge circuit

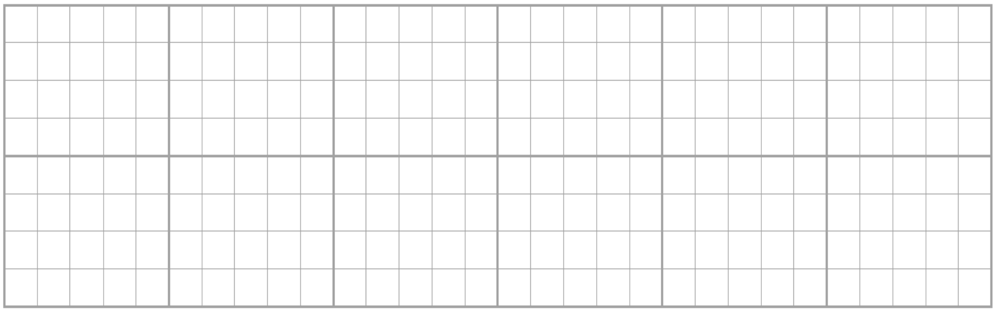
Measure the AC voltage at the transformer secondary.

Measure, with a voltmeter, the DC voltage across resistor R_L.

Measure, with a voltmeter, the DC voltage across the diodes.

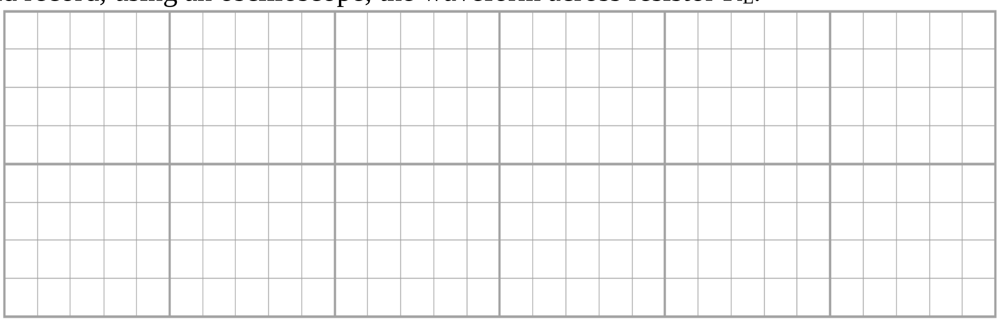
Voltages to measure	Measured values	Units
Secondary voltage (AC)		
Load resistance voltage (DC)		
Diode D1 voltage (DC) Diode D2 voltage (DC) Diode D3 voltage (DC) Diode D4 voltage (DC)		

Measure and record, using an oscilloscope, the waveform across each diode. Make sure to connect the probe to the diode.



Draw the obtained image here.

Measure and record, using an oscilloscope, the waveform across resistor R_L.



Draw the recorded image here.

Section 3

Questionnaire for final report

For the implemented half-wave rectifier, prepare a comparative table as shown. Do you find these values equal to those from the simulation performed?

1

Order	Theoretical value	Experimental value	Margin of error
Secondary voltage (AC)			
Load resistance voltage (DC)			
Diode voltage (DC)			
Load resistance voltage with an inverted diode (DC)			
Inverted diode voltage (DC)			

2 Explain the reason why the voltage across the diode is negative.

3 What is the value of the peak inverse voltage that the diode can withstand?

4 What is the usefulness of the voltage obtained across the resistor, and how can a more stable, continuous voltage be achieved?

5 Research what happens if we place a capacitor in parallel with the load resistance of the circuit. What would the waveform be?

6 Where and what are half-wave rectifiers used for?

7 For the implemented half-wave rectifier, prepare a comparative table as shown. Do you find these values equal to those from the simulation performed?

Order	Theoretical value	Experimental value	Margin of error
Secondary voltage (AC)			
Load resistance voltage (DC)			
Diode D1 voltage (DC)			
Diode D2 voltage (DC)			
Diode D3 voltage (DC)			
Diode D4 voltage (DC)			

8 How can a full-wave rectifier be generated using two diodes? Draw the circuit and explain.

Conclusions

Write at least five conclusions and recommendations about the topic, the experiment, and the safety aspects of laboratory practices.

References

Floyd, T. (2008). Electronic devices. Pearson Education. https://doi.org/ISBN978-970-26-1193-6

4.3. Validation Test of Laboratory Practice Guides for the Analog Electronics Course

To evaluate the effectiveness of the laboratory practice guides for the Analog Electronics course and their ability to improve learning, a structured questionnaire was administered to 35 randomly selected students from the Analog Electronics course at two different times:

4.3.1. Before using the Guides (Pretest)

Students answered a questionnaire that included questions about the operation of half-wave and full-wave rectifier circuits, interpretation of waveforms, technical parameters of diodes, and practical applications, which allowed establishing an initial level of theoretical and practical understanding.

4.3.2. After using the Guides (Posttest)

The guides containing theoretical information were handed out, and the guides were provided, containing theoretical information, practical steps, simulations, questionnaires, and references, integrated into each laboratory guide. Students completed the questionnaire again, applying the knowledge acquired through the guide and practical activities in the laboratory.

The collected data were statistically analyzed using the Student's t-test for related samples, comparing the results before and after the intervention, which allowed measuring the improvement in understanding and application of concepts and evaluating the functionality of the guides as an educational tool, verifying their ability to facilitate students' theoretical and practical learning.

This methodological approach is supported by recent studies that apply pre- and post-intervention evaluations with structured questionnaires to measure the effectiveness of didactic resources in Analog Electronics.

For example, Rodriguez Sarda [6] developed a similar proposal to strengthen self-learning through practical guides, using statistical analysis to demonstrate significant improvements in technical and conceptual competencies.

Likewise, Toaza [7] evaluated didactic tools through quantitative and qualitative analyses for electrical circuits, validating the use of questionnaires and structured practical material to promote learning.

Gil [8] reviewed methodologies in basic electronics that include pre- and posttests and evaluated the positive impact of practical activities with virtual and in-person laboratories on student comprehension, in order to support the effectiveness of the method used to evaluate guides as an innovative educational resource that facilitates the integration of theory and practice in higher technological education.

4.3.3. Questionnaire

Table 7. Questionnaire

No	Question	Scale (1-5)
1	I understood how a half-wave rectifier circuit works.	1 2 3 4 5
2	I was able to explain the differences between a half-wave rectifier and a full-wave rectifier.	1 2 3 4 5
3	I understood the importance of reverse peak voltage in diode behavior.	1 2 3 4 5
4	I was able to relate the theoretical voltage and current values to the values measured in the laboratory.	1 2 3 4 5
5	I understood how reverse recovery time affects the response of a diode.	1 2 3 4 5
6	I was able to interpret the waveforms obtained on the oscilloscope during the practical session.	1 2 3 4 5
7	I identified the practical applications of rectifiers in electronic systems.	1 2 3 4 5
8	I recognized the most relevant technical parameters of the 1N4007 diode and its application in the circuits implemented.	1 2 3 4 5
9	I was able to explain what happens when a capacitor is added in parallel with the load resistance of a rectifier.	1 2 3 4 5
10	I believe I gained a comprehensive understanding of rectifiers and their application in analog electronics.	1 2 3 4 5

4.3.4. Scale

The Likert scale is a psychometric instrument widely used in educational and social research to measure attitudes, opinions, or perceptions [9]. It is based on a series of statements or questions to which participants respond by indicating their degree of agreement or disagreement on an ordinal scale, usually with 5, 7, or 10 points, although the 5-point scale is the most common due to its balance between detail and ease of response [10, 11]. The main characteristics of the scale include that it is ordinal-the values show an order, but the differences between values do not represent an exact magnitude-and that it is flexible, allowing the number of points to be adapted according to the study's needs and its easy interpretation has made it very popular in teaching evaluations, attitude measurement, and perception analysis in educational and social contexts [9, 12].

Table 8. Interpretation

Value	Interpretation
1	Strongly disagree / I did not understand anything
2	Disagree / I understood very little.
3	Neither agree nor disagree / Partial understanding.
4	Agree / I understood quite a bit.
5	Strongly agree / I understood completely.

4.3.5. Results

Table 9. One-Sample Statistics

	N	Mean	Standard Deviation	Standard Error Mean
STATE_1	35	27,3429	3,62948	,61349
STATE_2	35	44,8286	,95442	,16133

Table 10. Test for a sample

	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
STATE_1	44,569	34	,000	27,34	26,096	28,5896
STATE_2	277,874	34	,000	44,82	44,500	45,1564

Test Value = 0

Table 11. One-Sample Effect Size

		Standardizer[a]	Point Estimate	95% Confidence Interval	
				Lower	Upper
STATE_1	Cohen's d	3,62948	7,534	5,717	9,343
	Hedges' correction	3,71207	7,366	5,590	9,135
STATE_2	Cohen's d	,95442	46,969	35,844	58,072
	Hedges' correction	,97614	*45,924*	35,046	56,780

a. The denominator used in estimating the effect sizes. Cohen's d uses the sample standard deviation. Hedges' correction uses the sample standard deviation, plus a correction factor

4.3.6. Interpretation of Results

The results of the statistical analysis show the impact of using laboratory practice guides on students' understanding of analog electronics rectifier circuits.

Descriptive Statistics

In the pretest (STATE_1), administered before using the guides, the 35 students obtained a mean of 27.34 with a standard deviation of 3.63 and a standard error of 0.61, indicating that the scores were relatively dispersed around the mean, reflecting an initial level of partial understanding of theoretical and practical concepts. After the intervention (STATE_2), the mean increased to 44.83 with a standard deviation of 0.95 and a standard error of 0.16, showing that the scores concentrated on higher and more homogeneous values, evidencing a notable improvement in content comprehension after using the guides.

4.3.7. Student's T-Test

The one-sample t-test comparing the means with the test value equal to 0 showed statistically significant results in both cases:

- Pretest: $t = 44.569$, $df = 34$, $p < 0.001$
- Posttest: $t = 277.874$, $df = 34$, $p < 0.001$

These values confirm that the means at both time points differ significantly from 0, indicating that the obtained scores are statistically different from a null level of understanding, and the 95% confidence interval shows that the students' true mean is within ranges clearly superior to the initial value, reinforcing the relevance of the observed change.

4.3.8. Effect Size

The analysis of effect sizes using Cohen's d and Hedges' correction reveals that:

Pretest (STATE_1) presents a Cohen's d of 3.63 and Hedges of 3.71, indicating a large effect, though smaller than the subsequent one.

Posttest (STATE_2) reaches a Cohen's d of 0.95 and Hedges of 0.97, representing a very large effect.
This shows that the intervention with the guides had a considerable impact on learning, significantly improving both conceptual understanding and practical application of rectifier concepts in students.

5. Results and Quantitative Analysis

The implementation of the laboratory guides produced measurable and statistically significant improvements across all evaluated dimensions and students' average score increased from 11.4 in the diagnostic test to 16.8 in the final achievement test, demonstrating a solid learning gain and the statistical analysis confirmed that this improvement was significant (t-test, $p < 0.001$), and the effect size (Cohen's d = 1.21) corresponded to a high magnitude of impact and procedural competencies assessed through checklists also showed substantial progress and the performance rising from 62% to 88%, particularly in areas such as correct instrumentation handling, circuit assembly accuracy, and verification of measurement procedures.

In addition, 83% of students reported that the structured format of the guides enhanced their autonomy and reduced uncertainty during laboratory activities, and this validates the effectiveness of the guides in strengthening both technical and procedural learning while contributing to the standardization of laboratory practices.

6. Comparative Analysis with Existing Research

The results obtained align with previous studies that emphasize the value of hands-on experimentation and active learning in engineering education; however, unlike much of the existing literature, this study provides structured and empirically validated didactic tools specifically tailored to the context of technological higher education.

Prior research frequently highlights conceptual benefits or motivational gains but often lacks standardized instruments or quantitative validation, and by contrast, the present study advances the field by demonstrating that a set of systematically designed laboratory guides can generate high effect sizes and consistent improvements in procedural performance.

This contribution bridges a documented gap in the literature regarding the development and empirical evaluation of standardized materials for analog electronics laboratories, which is seldom addressed in studies focused primarily on simulations or general methodological recommendations.

7. Discussion

The findings indicate that the use of structured laboratory guides contributes to reducing ambiguity in experimental activities and improves the coherence between theoretical content and practical application, promotes greater student autonomy and the significant learning gains and high effect size obtained suggest that the guides are not merely supportive tools but effective pedagogical mechanisms for closing learning gaps commonly observed in technological institutes, particularly following the instructional disruptions caused by the COVID-19 pandemic and the inclusion of digital elements such as QR codes for accessing resources enhances flexibility and aligns with current educational models that integrate physical and digital learning environments and compared with studies that prioritize virtual simulations or isolated interventions. This research provides a more comprehensive approach that integrates didactic design, competency-based assessment, and quantitative validation within real laboratory conditions. Although the intervention was implemented within a single academic program, the structure and pedagogical design of the laboratory guides allow broader application across other courses in electronics, electrotechnics, instrumentation, mechatronics, and introductory engineering laboratories. The modular nature of the guides, combining conceptual review, structured procedures, self-assessment questions, and digital access components, facilitates easy adaptation to different competency levels, and this broader applicability positions the proposed guides as a flexible tool for strengthening laboratory-based teaching while maintaining alignment with competency-based curricula across multiple technological programs.

8. Implications for Practice and Educational Policy

The results underscore the need for technological institutes to adopt structured and validated laboratory materials that ensure consistency in practical instruction.
The guides developed in this study represent a scalable resource capable of standardizing laboratory activities, supporting teachers, and enhancing student performance in analog electronics, from an educational policy perspective.

The findings support the incorporation of validated didactic tools into institutional and national guidelines for technological education, particularly in programs related to electronics and industrial technologies, and the evidence presented also highlights the relevance of strengthening laboratory-based learning as a key strategy for aligning technical education with the skills demanded by Industry 4.0.

9. Limitations and Future Research

The study was conducted with a small sample from a single academic program, which may limit the generalizability of the findings. Future research should replicate the intervention in multiple institutions and across different cohorts to validate the scalability of the results. Although the results are promising, this study was conducted within a single institution with a limited sample size, which may restrict the generalizability of the findings and replication in additional technological institutes and diverse regions would contribute to validating the robustness of the results and the future research could also examine the long-term retention of competencies acquired through the guides, particularly during professional internships or workplace training, additionally, integrating virtual or remote laboratory components into the existing guide structure represents a promising opportunity for expanding hybrid learning models in technological education.

10. Conclusion

The design of laboratory practice guides for the Analog Electronics course constitutes an innovative pedagogical strategy that contributes to strengthening self-learning in technological education students. The presented proposal allowed for the standardization of the practice structure, integrating clear objectives, theoretical foundations, experimental procedures, and evaluation criteria that ensure coherence with curricular objectives. The results obtained from the teaching validation demonstrate that these guides can improve the relationship between theory and practice, foster student motivation, and promote the balanced development of technical, procedural, and socio-emotional competencies, and likewise, they offer a systematized resource that facilitates teaching work, reduces improvisation in the laboratory, and generates useful indicators for continuous institutional improvement.

It is concluded that the implementation of laboratory guides as a teaching resource not only strengthens autonomous learning but also contributes to raising the quality of teaching in technological engineering programs, responding to the training challenges of Industry 4.0 and the post-pandemic context. Finally, an application test of the guide's use was conducted, and the results obtained from the pretest and posttest questionnaires confirm that the use of laboratory practice guides significantly improves students' theoretical and practical understanding, additionally demonstrating no progress in their ability to apply rectifier concepts in experimental situations.

This demonstrates the effectiveness of the guides as a pedagogical tool, since the clear organization of objectives, content, and procedures not only facilitates autonomous learning but also strengthens the connection between theory and practice, promoting comprehensive development of technical, methodological, and socio-emotional competencies in technological education students.

References

[1] Armando Acosta Iglesias, Carlos Alberto Gato Armas, and Jesús González Rodríguez, "Practical Training through University-Business Integration: Principles, Scientific Ideas and Stages," *Mendive. Journal of Education*, vol. 19, no. 4, pp. 1247-1264, 2021. [Google Scholar] [Publisher Link]

[2] Rui M. Lima et al., "Mapping the Implementation of Active Learning Approaches in a School of Engineering-The Positive Effect of Teacher Training," *European Journal of Engineering Education*, vol. 49, no. 5, pp. 945-964, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[3] John Biggs, and Catherine Tang, Gregor Kennedy, *Teaching for Quality Learning at University*, 5th ed, McGraw-Hill Education, 2022. [Google Scholar] [Publisher Link]

[4] Rui M. Lima et al., “Mapping the Implementation of Active Learning Approaches in a School of Engineering-The Positive Effect of Teacher Training,” *European Journal of Engineering Education*, vol. 49, no. 5, pp. 945-964, 2024. [CrossRef] [Google Scholar] [Publisher Link]
[5] Martha Díaz Flores et al., *Research Methodology. Editorial Trillas*, SA de CV, 2013. [Google Scholar]
[6] René Rodríguez Sarda, “Teaching Innovation Strategy to Promote Autonomous Learning of Students in Marketing Subjects from a Guide,” *Science and Education*, vol. 5, no. 3, pp. 6-16, 2024. [CrossRef] [Google Scholar] [Publisher Link]
[7] Alexis Abraham Aldaz Toaza, “Educational Tools for Learning About Electrical Circuits in the Unified General Baccalaureate,” *Repository National*, PUCE, 2024. [Google Scholar] [Publisher Link]
[8] Julieth Osmeydy Parra-Gil, Edgar Orlando Caro, and Jovani Alberto Jiménez-Builes, “Review of Teaching and Learning Strategies for basic Electronics Aimed at new Engineering Students,” *Dyna*, vol. 90, no. 227, pp. 176-184, 2023. [Google Scholar]
[9] Angelica Maria Fabila Echauri, Hiroe Minami, and Manuel Jesús Izquierdo Sandoval, “The Likert Scale in Teacher Evaluation: An Approach to its Characteristics and Methodological Principles,” *Teaching Perspectivas*, vol. 50, pp. 31-40, 2012. [Google Scholar] [Publisher Link]
[10] Antonio Matas, “Design of the Likert-Type Scale Format: A State of the Art,” *Electronic Journal of Educational Research*, vol. 20, no. 1, pp. 38-47, 2018. [Google Scholar]
[11] Malcolm Koo, and Escala Tipo Likert, “Likert-Type Scale,” *Encyclopedia*, vol. 5, no. 1, pp. 1-11, 2025. [CrossRef] [Publisher Link]
[12] María del Carmen Romero, and María Belén Álvarez, “Uses of the Term “Likert”: A Review of Organizational Learning Studies,” *Journal of the School of Improvement in Operational Research*, vol. 30, no. 51, pp. 41-57, 2022. [Google Scholar] [Publisher Link]
[13] Archana Mantri et al., “Design and Evaluation of a PBL-based Course in Analog Electronics,” *IEEE Transactions on Education*, vol. 51, no. 4, pp. 432-438, 2008. [CrossRef] [Google Scholar] [Publisher Link]
[14] Bonni H. Ferri et al., “Effects of In-Class Hands-On Laboratories in a Large Enrollment, Multiple Section Blended Linear Circuits Course,” *Advances in Engineering Education*, vol. 5, no. 3, pp. 1-27, 2016. [Google Scholar] [Publisher Link]
[15] Kenneth Ray Hite et al., “An Online Approach to the Analog Electronics Laboratory,” *2019 ASEE Annual Conference and Exposition*, Tampa, Florida, 2019. [CrossRef] [Google Scholar] [Publisher Link]
[16] Kenneth A. Connor et al., “Using the Mobile Studio to Facilitate Non-Traditional Approaches to Education and Outreach,” *2011 ASEE Annual Conference and Exposition*, Vancouver, BC, 2011. [CrossRef] [Google Scholar] [Publisher Link]
[17] Robert W. Hendricks, Ka Ming Lai, and James B. Webb, “Lab-in-a-Box: Experiments in Electronic Circuits that Support Introductory Courses for Electrical and Computer Engineers,” *Proceedings of the 2005 American Society for Engineering Education Annual Conference and Exposition*, 2005. [Google Scholar]
[18] Walt Kester, A Complete Circuits Laboratory on Your Desk, in Your Backpack, and on the Go, *Analog Dialogue*, vol. 50, 2016. [Online]. Available: https://www.analog.com/en/analog-dialogue/studentzone/studentzone-december-2016.html
[19] Konstantinos B. Baltzis, and Konstantinos D. Koukias, “Using Laboratory Experiments and Circuit Simulation IT Tools in an Undergraduate Course in Analog Electronics,” *Journal of Science Education and Technology*, vol. 18, no. 6, pp. 546-555, 2009. [CrossRef] [Google Scholar] [Publisher Link]
[20] Hui Wang et al., “The Practice and Exploration of the Course of Electronic Circuit Fundamental based on E-learning Environment,” *Teaching and Learning with Technology: Proceedings of the 2016 Global Conference on Teaching and Learning with Technology (CTLT 2016)*, pp. 263-269, 2017. [CrossRef] [Google Scholar] [Publisher Link]
[21] Devika Kataria, and Gustavo Sanchez, “Design on Project-based Learning for Analog Circuits,” *2020 IEEE Frontiers in Education Conference (FIE)*, Uppsala, Sweden, pp. 1-4, 2020. [CrossRef] [Google Scholar] [Publisher Link]
[22] Faisal Mohd-Yasin, “Effective Strategies for Project-based Learning of Practical Electronics,” *Electronics*, vol. 10, no. 18, pp. 1-13, 2021. [CrossRef] [Google Scholar] [Publisher Link]
[23] Christos Tokatlidis et al., “Hands-on and Virtual Laboratories in Electronic Circuits Learning-Knowledge and Skills Acquisition,” *Information*, vol. 15, no. 11, pp. 1-20, 2024. [CrossRef] [Google Scholar] [Publisher Link]
[24] Zamzami Zainuddin et al., “How Do Students Become Self-Directed Learners in the EFL Flipped-Class Pedagogy? A Study in Higher Education,” *Indonesian Journal of Applied Linguistics*, vol. 8, no. 3, pp. 678-690, 2019. [CrossRef] [Google Scholar] [Publisher Link]
[25] Blerta Prevalla Etemi et al., “The Effect of the Flipped Learning Approach on Engineering Students’ Technology Acceptance and Self-Directed Learning Perception,” *Sustainability*, vol. 16, no. 2, pp. 1-20, 2024. [CrossRef] [Google Scholar] [Publisher Link]