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Learning competencies in the electrical installations laboratory for engineering students

Margarita F. Murillo Manrique[1,2], Jorge A. Sánchez Ayte[3], Antonio A. Meléndez Murillo[4]
[1]Professional School of Mechatronic Engineering, Faculty of Engineering, Ricardo Palma University, Lima, Perú
[2]Professional School of Mechanical and Electrical Engineering, Head of the Electrical Installations Laboratory, National Technological University of Lima South, Lima, Perú
[3]Professional School of Mechanical and Electrical Engineering, Head of the Thermodynamics, Statics, and Dynamics Laboratory, National Technological University of Lima South, Lima, Perú
[4]Data Analysis Consultant, National University of Engineering, Lima, Perú

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ABSTRACT

The research addresses the lack of practical competencies in the electrical installations-I (IE-1) course at the School of Mechanical and Electrical Engineering (EPIME) at the National Technological University of Lima Sur, where the current content is mostly theoretical. To solve this problem, the course was moved to the Electrical Installations Laboratory (LABIE) and the conceive, design, implement, and operate (CDIO) methodology was applied, combining theory with practice to develop competencies in knowledge, skills, and attitudes. The laboratory guides were aligned with the new IE-1 syllabus, including single-phase and three-phase systems of 220 V at 60 Hz, which were not previously covered. Two groups of 15 students were compared: an experimental group (EG) and a control group (CG). Both took a pre-test with similar results. The CG followed traditional classes, while the EG worked in the LABIE with CDIO. At the end, a post-test showed significant improvements in the EG, validating the effectiveness of CDIO in enhancing practical training in IE-1. It is concluded that this methodology should be implemented in the new EPIME curriculum.

Corresponding Author:

Margarita F. Murillo Manrique
Professional School of Mechatronic Engineering, Faculty of Engineering, Ricardo Palma University
Av. Alfredo Benavides 5440, Santiago de Surco 15039, Lima, Peru
Email: margarita.murillo@urp.edu.pe

1. INTRODUCTION

Contemporary challenges in competitiveness and industrial productivity demand a new generation of engineers with innovative capabilities and solid technical foundations. In this context, educational institutions face the responsibility of promoting skills that drive innovation at the national level, addressing technological, sustainability and social development aspects. However, recent research has shown significant deficiencies in the laboratory infrastructure of state universities, in some cases reaching a total lack of technological equipment [1].

In particular, the National Technological University of Lima Sur (UNTELS) is a young university with 23 years of presence in higher education, therefore, it faces the challenge of updating its educational approach to adapt to the demands of the contemporary industrial world. At the School of Mechanical and Electrical Engineering (EPIME), the course electrical installations-I (IE-1) is taught mainly through traditional methods, limiting student interaction with practical experiences. Although tools such as AutoCAD are occasionally used to design electrical plans in the computer laboratory, the lack of adequate infrastructure for practice hinders the comprehensive development of future mechanical and electrical engineers [2]. The relevance of the laboratory in the training of engineers is unquestionable. Not only because it reinforces the theoretical knowledge it supports [3], but also because it offers a space to solve practical problems and develop technical skills. That the integration between theory and practice is essential because it allows students to understand their profession in a broader context, which includes economic, social and cultural aspects [3], [4].

To address these challenges, the EPIME has initiated the renovation of the Electrical Installations Laboratory (LABIE) [1]. This update, scheduled for the 2024-II semester, seeks to introduce new learning modules, measurement equipment and electrical accessories that facilitate the teaching of single-phase and three-phase low-voltage electrical installations with levels of 220 V at 60 Hz, as specified in the new syllabus [5]. This practical approach not only verifies and clarifies concepts, but also promotes the discovery of principles and laws of electricity, which govern the use of the electrical power system, thus establishing a valuable interrelation with the real world. The preliminary results of this initiative, validated in the 2023-II academic cycle, are the reason for the study of this research. Therefore, the theory of experiential learning [6], is supported by four different learning methods, concrete experience, reflective observation, abstract conceptualization and active experimentation, which is directly linked to current challenges in education.

Currently, education is linked to the internationalization and globalization of knowledge and the economy, posing a challenge for institutions to promote processes of research, innovation, creativity, and entrepreneurialism [7], [8]. This panorama of change is deepened by the new paradigm of higher education based on skills and professional profiles. This approach requires rethinking the design, development and evaluation of training. Consequently, professional competence, is the result of the integration of a complex set of knowledge, skills and professional values [9], [10].

The profile of EPIME students represents the model of professionals for the industry, which is based on curricular structures and is reflected in the new syllabus [5]. This model encompasses training aspirations, objectives, qualities, functions, areas of knowledge, skills, values and attitudes. The student who seeks alternatives, solutions, and ways out on their own demonstrates an understanding of their role in the process of autonomous learning and acknowledges their ability to continue learning even in the absence of the teacher [10], [11]. This situation is sought to be promoted with this research.

In addition to updating the infrastructure, it is mandatory to evaluate the effectiveness of these interventions in developing competencies and skills in students. In this regard, it is proposed to use the conceive, design, implement, and operate (CDIO) methodology to assess three important dimensions: knowledge, skills, and attitudes [12]–[14]. Consequently, this methodology, focused on experiential learning and problem-solving, aligns with the current demands of engineering education and promotes the holistic development of future professionals [11].

Following the CDIO methodology [14], [15], in the "Conceive" phase, the project needs are defined, considering technology, strategies, and regulations for the conceptual and technical plan; in our case, this is established according to the standards of the National Electrical Code (NEC-U). In the "Design" phase, the schematics, graphs and diagrams are created; in our case, the electrical plans and standardized representations are designed using the AutoCAD software. In addition, the descriptive memory of the technical file is developed detailing the procedure for the implementation in Word and Excel formats, in the "Implement" phase, the design is transformed into a product, which involves coding, testing, and validation. In our case, this is carried out in the learning modules, where electrical circuits, conduits, panels, and electrical accessories are included, following the standards of the NEC [16]. The final phase, called "Operate," consists of commissioning the implemented circuits, including maintenance, optimization, and system presentation. In our case, this stage allows us to verify the measurements of voltage levels, current, and maximum demand defined in the project's conception, in accordance with established regulations [16], as shown in Figure 1.

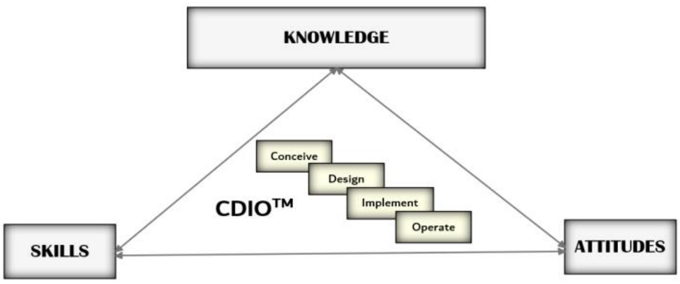

Figure 1. Dimensions for learning by competencies

In summary, this research aims to explore the impact of LABIE renovation and the implementation of innovative practices with project-based learning (PBL) on the training of electrical mechanical engineers at UNTELS. In the PBL methodology [17], there is still room for improvement in the interrelation with the subject, peer assessment, coordination with project members, and data collection and analysis. With these practices, we aim to contribute to the development of a dynamic educational environment tailored to the needs of the contemporary job market [18].

2. METHOD

The research is a descriptive study with a quantitative approach of quasi-experimental design. For the evaluation of the dependent variable learning by competencies, a sample of 30 sixth-semester students from the EPIME enrolled in the IE-1 course was taken. The section was divided into two groups, a control group (CG) with 15 male students and an experimental group (EG) with 15 students (14 males and 1 female).

One of the main limitations of this study is the small sample size, which is due to the availability of only one section of the IE-1 course. Although small, this sample size is representative of the entire cohort of students enrolled in the course. Previous studies have indicated that samples of this size can be adequate for detecting significant differences in controlled and specific contexts [19]. In educational studies, a sample of 30 subjects can be sufficient to obtain statistically significant results, provided that appropriate analysis methods are used and other variables are controlled [20]. Additionally, the Kolmogorov-Smirnov (K-S) test is useful for validating results in small samples, comparing the final state of a group with its initial state, or comparing an experimental group with a control group [21].

Initially, a pre-test was administered to both the CG and EG. Subsequently, the experiment was conducted in the LABIE for the EG, based on the learning units (LU) of the course and according to the laboratory guides [5], [22]–[25]. Finally, the post-test was applied to both groups. The design scheme is shown in Figure 2. The research includes the students of the course of IE-1 at UNTELS-EPIME, the teachers and the academic documents used in the classroom and in the laboratory (syllabus, learning guides, rubrics and class plan). In this sense, the current syllabus was applied to the CG, while the conceive, design, implement, and operate (CDIO) syllabus and the laboratory guides were applied to the EG, with several studies [5], [24], [25] being the academic materials that are being validated. The contents of the syllabus are shown in Figure 3.

For units of learning (UA) 3 and 4, titled "Implement" and "Operate" respectively, Laboratory Guides have been developed for implementation in the learning modules at LABIE. UA-3 focuses on "Low-voltage electrical and electromechanical elements," while UA-4 addresses "Interpretation of electrical drawings and their implementation in low voltage" [23], [25]. These materials were used to assess competency-based learning at LABIE. For initial, process, and final evaluations, the system approved by UNTELS was applied, which is included in the new CDIO syllabus [5]. The assessment criteria are detailed in Table 1.

To design the research instrument, aligned with the dependent variable "competency-based learning" and the independent variable "electrical installations laboratory," an operationalization matrix was used. This matrix details the dimensions to be evaluated for the dependent variable, as well as the questionnaire items applied the GC and GE. In this regard, the number of items was considered according to the indicators for each dimension: for the dimension of knowledge about electrical installations, 9 items; for skills, 5 items (related to the design, installation, and operation of low voltage electrical circuits); and for attitudes, 6 items. In total, 20 items were applied before and after the experiment [5], [25]–[27]. The detailed distribution of these items is presented in Table 2.

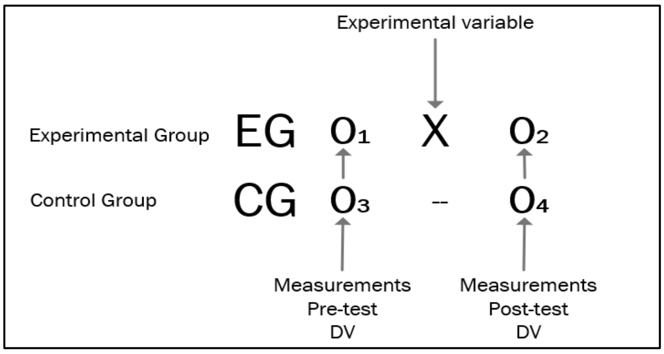

Figure 2. Research design outline

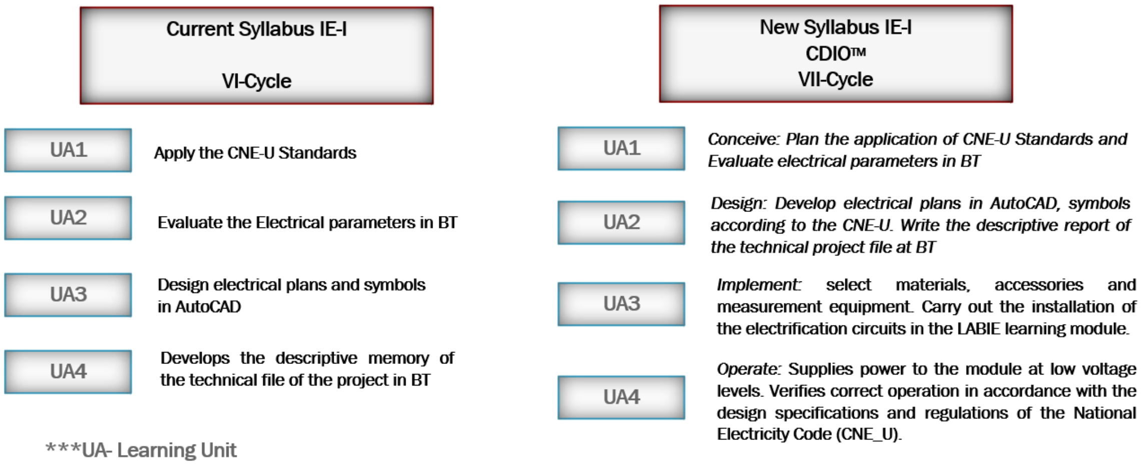

Figure 3. The current syllabus and CDIO syllabus

Table 1. Assessment criteria EPIME-UNTELS

Assessment		Code	Description	Value (%)
UA1	Capacity assessment	EC1	Learning evaluation of the first unit (project conception)	10
UA2	Capacity assessment	EC2	Learning evaluation of the second unit (plan design and descriptive memory)	10
Partial evaluation		EP	Partial subject exam	20
UA3	Capacity assessment	EC3	Learning evaluation of the third unit (implement-learning module, teamwork)	10
UA4	Capacity assessment	EC4	Learning evaluation of the fourth unit (operate-learning module, teamwork)	10
	Application work	TA	Formative research	20
Final evaluation		EF	Final subject exam	20

For each learning unit, four validation sessions of the pedagogical materials were conducted, totaling 16 sessions. Schedules were coordinated with GC and GE groups to conduct the pre-test, followed by the application of the learning guides (LG) to the GE [25]. During the face-to-face sessions at the LABIE facilities, competency-based learning before and after was assessed using the questionnaire instrument. The preparation and tabulation of quantitative data recorded in the evaluation instrument was carried out using the Kolmogorov-Smirnov test to determine the normality of the obtained data. The K-S test result was 0.038, a value lower than the theoretical p-value (0.05), indicating that the research variable is non-parametric. Therefore, the Mann-Whitney U test statistic was applied for data processing for small samples [21], [28]. Using the SPSS tool [29], [30], dataset was generated contrasting the competency-based learning variable with the hypothesis value, defined according to the dimensions of knowledge acquisition, skill development, and attitude improvement.

The evaluation of the knowledge questionnaire instrument, processed with the SPSS tool, allowed us to measure validity and reliability. For validity, the result showed a probability of occurrence of 0.000 (bilateral significance), which is less than 0.05, inferring that the item has content validity [30]. For reliability, Cronbach's alpha coefficient [31] was used for the various correlation matrices of each item. As shown in Table 3, α=0.895, which is greater than 0.5, so it is concluded that the test is reliable. In certain contexts, and by tacit agreement, values of alpha greater than 0.7 or 0.8 (depending on the source) are considered sufficient to guarantee the reliability of the scale [31].

3. RESULTS AND DISCUSSION

3.1. Initial conditions: result of the entry test in the CG and EG

In Table 4, it is observed that the averages in the entrance test are practically similar, with 7.79 and 7.75 points for the CG and EG, respectively. Moreover, the standard deviations of 1.581 and 1.514 relative to the mean indicate similarity. Regarding the Mann-Whitney U test, the Z statistic is -0.201, with a probability (p) equal to 0.841 (>0.05). Therefore, it is concluded that the CG and EG have similar performance on the entry questionnaire, demonstrating similarity in competency-based learning [28]–[30].

Table 2. Operationalization of the dependent variable

Dimensions	Indicators	Questionnaire	Items	Scale
I. Knowledge	1.1. Maneuver and protection elements	1. Which of the following electrical elements are considered switching and protection elements? Please select all correct options: a. Thermomagnetic key b. Power outlet c. Differential wrench d. Switch	1, 2, 3, 4, 5, 6, 7, 8, 9	1= Correct 0= Incorrect
	1.2. Power elements	2. Which of the following electrical elements are commonly used in control circuits? Please select all correct options: a. Low power contactors b. Switches c. Power outlet d. AC relays		
	1.3. Low voltage levels	3. Which of the following specifications indicates the low voltage level of the electrical system? a. 110 V 15 A b. 220 V 50 Hz c. 220 V 60 Hz d. 440 V 60 Hz.		
	1.4. Standards for selecting contactors	4. Which of the following standards is commonly applied to items such as contactors? a. IEC-ANSI b. NPT-IEC c. NFA-ANSI d. CNE-ANSI		
	1.5. Application of the voltmeter	5. What state of contacts can a voltmeter identify? a. NA-NC b. NC-S phase c. NA-R phase d. NA-continuity		
	1.6. Table of maximum electrical demand	6. What parameters can a maximum demand table evaluate? a. Power in KW of the loads b. Quantity of loads c. Installed power and demand factor d. Power factor		
	1.7. Feeder and branch circuits	7. To size the thermomagnetic switch (ITM), which consideration is correct? a. In (nominal current) less than Id (design current) b. ITM greater than Id (design current) c. Id equal to In (nominal current)		
	1.8. One-line diagram	8. The one-line diagram allows us to establish the characteristics of the circuits, as well as determines: a. Characteristics of the electrical panel b. Characteristics of the keys c. Characteristics of the conductors d. Maintenance of the circuits		
	1.9. Grounding system-PAT	9. According to regulations, what is the value of the resistivity of the PAT (earthing) system for a multi-family home? a. 22 Ohm b. 15 Ohm c. 8 Ohm d. 5 ohm		
II. Skills	2.1. Electrical and electromechanical materials and equipment	10. They use materials and equipment correctly, following the manufacturer's technical specifications	10, 11, 12, 13, 14	1= Yes 0= No
	2.2. Learning modules	11. They participate competitively in solving practical problems related to the implementation of electrical circuits in the learning modules		
	2.3. Technical problems	12. They effectively communicate the technical problems that arise during the implementation of electrical circuits, complying with LABIE safety standards		
	2.4. Technological advance	13. They develop and operate electrical circuits in the learning modules, using the corresponding elements and devices, and compare the results with simulators and software in line with technological advances		
	2.5. Resources at LABIE	14. They manage the electrical resources available to effectively carry out the activities that contribute to the achievement of the competencies in the LABIE		
III. Attitudes	3.1. Responsibility 3.2. Commitment 3.3. Initiative 3.4. Leadership 3.5. Participation	15. They reflect on their responsibility in LABIE, assessing the consequences of their actions 16. They are committed to the proposed goals and collaborate effectively to achieve significant learning 17. They demonstrate initiative by completing assigned tasks and undertaking others on their own initiative, contributing to the benefit of the group 18. They actively participate in the activities of other teams and collaborate to successfully achieve the proposed objectives 19. They actively contribute to changes in the environment, adding value and inspiring their colleagues to participate in collaborative work. 20. They participate in activities outside of LABIE, contributing to the development of social projects	15, 16, 17, 18, 19, 20	1= Yes 0= No

Table 3. Reliability analysis: input and output questionnaire

Cases	N	%	Cronbach's alpha	N elements
Valid	15	100.0	0.895	20
Excluded[(a)]	0	0		
Total	15	100.0		

a. List deletion based on all variables in the procedure

Table 4. Mann-Whitney U test to compare the competency-based learning between CG and EG

Statistical	Cluster		Mann-Whitney U test
	Control (n=15)	Experimental (n=15)	
Average	7. 79	7.75	Z=-.201
Standard deviation	1.581	1.514	*p*=.841

3.1.1. Results by dimensions in the entry test

As presented in Table 5, the analysis of the three dimensions is presented: knowledge acquisition, skill development, and attitudes. For the normality test, values of 0.003, 0.000, and 0.003 were found, indicating that they do not follow a normal distribution. Therefore, the Mann-Whitney U test was applied, with results showing a probability >0.05, demonstrating that the means in the entry test are equal. Consequently, it is concluded that both groups have similar conditions before the application of the learning guides in the LABIE. Additionally, it is observed that the averages obtained for the dimensions of knowledge acquisition (CG=3.14, EG=3.21), skill development (CG=1.93, EG=1.82), and attitudes (GC=2.71, GE=2.71) are close values, indicating that the learning of the CG and EG are similar before the experiment [28]–[30].

Table 5. Mann-Whitney U test to compare the learning by CG and EG competencies

Dimensions	Cluster	Average	SD	K-S		Mann-Whitney U test		
				Z	p	U	Z	p
Knowledge acquisition	Control	3.14	1.239	1.79	0.002	367	-0.425	0.671
	Experimental	3.21	1.067					
Skill development	Control	1.93	0.716	2.164	0.001	362	-0.549	0.583
	Experimental	1.82	0.612					
Attitudes	Control	2.71	0.854	1.79	0.003	392	0	1
	Experimental	2.71	0.854					

Likewise, the evaluations conducted through the rubric revealed very low scores both in skills (designing, implementing, and operating) and in attitudes. These results underscore the need for the engineering student profile to be linked to a learning environment that simulates real-world conditions [24]. Engineers must be capable of manufacturing and processing engineering goods, products, and processes, installing and dismantling equipment and systems, maintaining and repairing infrastructures, assessing and testing systems and products, and providing services in the field of engineering [32]–[34].

3.2. Final conditions: results of the exit test in the control and experimental groups (result by dimensions)

3.2.1. Knowledge acquisition

As shown in Table 6, it is observed that, after the application of the exit questionnaire, the results were 3.55 for the CG and 6.41 for the EG. This suggests that, on average, participants in the experimental group showed a significantly higher level of knowledge acquisition compared to those in the control group. Additionally, regarding the variation of individual scores, values of 1.050 for the CG and 0.821 for the EG were recorded. This indicates greater consistency in the results of the experimental group.

Table 6. Mann-Whitney U test to compare knowledge acquisition between CG and EG

Statistical	Cluster		Mann-Whitney U test
	Control (n=15)	Experimental (n=15)	
Average	3.55	6.41	Z=-6.152
Standard deviation	1.050	0.821	*p*=0.001

Note: The scores are not close to the normal distribution (K-S=1.378; g.l.=54; p=0.038)

In the same table, it can be observed that the Mann-Whitney U test has a statistic Z=-6.152 with p-equal to 0.001 (<0.05) [26]–[28]. These values confirm that the obtained means are different in both groups; allowing to conclude that the students of the EG achieved better results in knowledge acquisition after the implementation of the UA in the LABIE. Therefore, the research hypothesis (H. $\mu 1 \neq \mu 2$) is accepted since the means are different, with the EG being higher [28]–[30].

Furthermore, the evaluations of the EG obtained through the rubric yielded very good scores regarding knowledge acquisition (project conception, application of standards, formula development, identification of needs in low-voltage electrification projects), allowing us to understand that students improve their knowledge when they are engaged in practical application [34]–[36]. Knowledge (know-how, mastery of technologies, innovative capacity) constitutes the competitive advantage of current and future organizations. Therefore, human capital takes the form of knowledge, education, skills, experiences, practices, routines, creativity utilization, and the development of relationships among individuals.

3.2.2. Skill development

Table 7 shows that in the exit test, the averages regarding skills development differ, being 2.61 for the CG and 4.07 for the EG. This indicates that, on average, participants in the EG exhibited significantly higher skills. Additionally, there is a variation in scores of 0.786 and 0.766 points regarding the mean, suggesting greater consistency of data in the EG. Furthermore, it is observed that, in the normality test, the p-value of 0.026 is less than 0.05, leading to the conclusion that the data do not follow a normal distribution.

Table 7. Mann-Whitney U test to compare the skill development between CG and EG

Statistical	Cluster		Mann-Whitney U test
	Control (n=15)	Experimental (n=15)	
Average	1.95	2.82	Z=-4.650
Standard deviation	0.465	0.420	*p*=0.001

Note: The scores are not close to the normal distribution (K-S=1.705; g.l.=54; p=0.002)

Regarding the Mann-Whitney U test, the Z statistic is -5.280 with a p of 0.000 (<0.05). This finding confirms a significant difference between the two groups in terms of the measured variable, suggesting that participants in the experimental group performed better after the implementation of the unit of learning. Therefore, the research hypothesis (H_1: $\mu1\neq\mu2$) is accepted, as the means are different, with a higher one in the experimental group [28]–[30].

Furthermore, evaluations of the experimental group obtained through the rubric revealed excellent scores in the development of skills, such as designing, implementing, and operating low-voltage electrification projects. These results suggest that practice significantly enhances students' knowledge in this specific area. Therefore, mental operations, defined as thinking skills, play a fundamental role in processing received information [36].

3.2.3. Change of attitude

As presented in Table 8, it is shown that in the exit test, the averages regarding attitude are different, being 2.61 for the CG and 4.07 for the EG; likewise, the scores vary by 0.786 and 0.766 points from the mean, indicating a greater concentration of data in the EG. Additionally, it is observed that in the normality test, the p-value of 0.026 is <0.05, demonstrating that the data are not normally distributed. Regarding the Mann-Whitney U test, the Z-statistic is -5.280 with a p equal to 0.000 (<0.05). This indicates that the means are different in both groups; with the EG obtaining better results after the application of the learning guides; therefore, the research hypothesis (Hi. $\mu1\neq\mu2$) is accepted, since the means are different, with the EG being higher [28]–[30].

Table 8. Mann-Whitney U test for comparison attitude between CG and EG

Statistical	Cluster		Mann-Whitney U test
	Control (n=15)	Experimental (n=15)	
Average	2.61	4.07	Z=-5.280
Standard deviation	0.786	0.766	*p*=0.000

Note: The scores are not close to the normal distribution (K-S=1.705; g.l.=54; p=0.0026)

After conducting assessments using the rubric, significant improvements were observed in the students' attitude change, particularly in aspects such as interaction, participation, teamwork, decision-making, and responsibility. These results indicate a notable improvement in the learning process when students actively participate in educational practices. This change in attitude is closely related to the competency-based approach, especially in the behavioral domain, which is crucial given the importance of the ability to effectively interact in contemporary work environments. Nowadays, companies actively value employees who possess key competencies and a proactive attitude to maintain competitiveness [36].

Figure 4 shows the pass and fail percentages of the EG before and after the experiment in the LABIE. It is observed that there is a significant increase in the acquisition of knowledge, with pass rates rising from 17% to 62.5%. Regarding skill development, there was a considerable improvement, with pass rates increasing from 4.1% to 46.5%. Finally, in terms of attitude, there was a notable increase, with the percentage of students receiving higher grades rising from 13.6% to 55.35% [12], [23]. In terms of failures, the percentages show a significant reduction in each case.

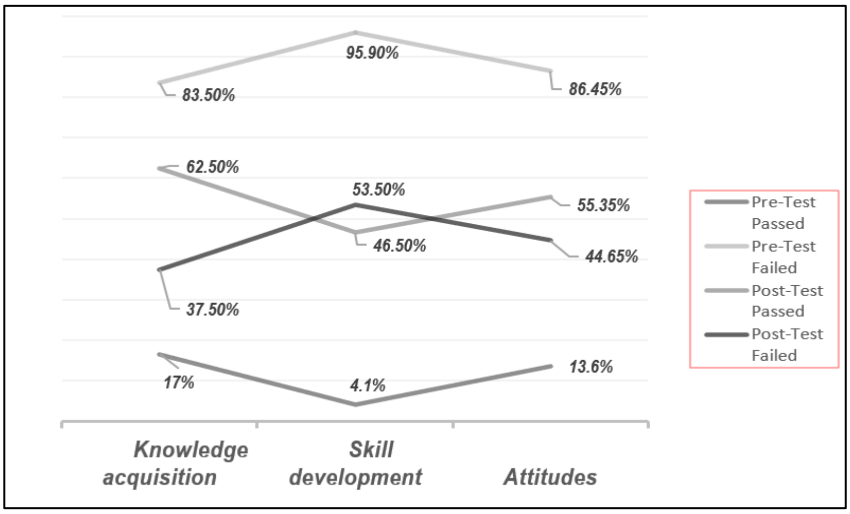

Figure 4. Performance before and after the experiment in the GE

4. CONCLUSION

The implementation of Learning Guides in the Electrical Installations Laboratory, as an integral part of the electrical installations-I course, has had an extremely positive impact on the development of competencies among EPIME students. Student feedback indicated that the performance of the equipment, materials, and accessories available in the laboratory were crucial in facilitating and supporting the development of skills related to the implementation and operation of low-voltage electrical installations. These opinions were supported by the results obtained in the competency assessment, where a significant improvement was observed in: knowledge acquisition, skills development, and attitude change in the students of the experimental group after the application of the learning guides. It is proposed to provide greater content specification in the LABIE guides, focusing especially on the implementation and operation of circuits in the learning modules. The application of the CDIO methodology in the IE-1 course has strengthened the practical experience. This methodology could be applied to other courses in the same field, enhancing cooperation and knowledge exchange between industry and the university. It is recommended that the administration make adjustments in the time allocation for LU3 and LU4 to allow students adequate time for research and practice. Additionally, future studies should consider increasing the sample size to validate and expand the results obtained in this research.

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BIOGRAPHIES OF AUTHORS

Margarita F. Murillo Manrique is RENACYT P0039523 Research Professor at CONCYTEC. She is an Honorary Doctor from the Daniel Alcides Carrion University. She was Dean of the Faculty of Engineering and Management and director of EPIME at UNTELS. She has a Doctor in Education, a Master in Teaching and Educational Management and an Electrical Engineer. She is an Associate Professor appointed since 2009 at the Professional School of Mechanical and Electrical Engineering (EPIME) of the National Technological University of Lima South (UNTELS). She is also a professor at the Professional School of Mechatronic Engineering, Civil Engineering, and the Graduate School of Industrial Engineering at Ricardo Palma University. She has undergraduate studies in economic sciences, postgraduate studies in systems engineering. She completed her studies in the Internet of Things (IoT) diploma. She was an advisor and instructor in the Department of Education at the Peruvian Army Communications School-Ministry of Defense. She belongs to the research group in Robotics and Advanced Mechatronics (GI-ROMA) of the URP. She can be contacted at email: mmurillo@untels.edu.pe.

Jorge A. Sánchez Ayte is RENACYT P0066942, a mechanical engineer trained at the National University of Engineering (UNI) and with a Master's Degree in Educational Sciences with a mention in University Teaching, as well as a Diploma in Operations Management from the PUCP. Currently, he works as a university professor at the National Technological University of Lima Sur (UNTELS), in the School of Electrical Mechanical Engineering since 2017, and recognized by his registration as an inventor in Indecopi. His professional career includes positions as an electromechanical specialist in various companies, with a focus on renewable energy and air conditioning. In the academic field, he has made contributions in research and publications, especially on topics of renewable energy and higher education. He can be contacted at email: jsanchez@untels.edu.pe.

Antonio A. Meléndez Murillo has a bachelor's degree in Systems Engineering and an master's in Systems Engineering from the National University of Engineering (UNI). Antonio has an advanced certification and TOEFL in English from ICPNA. He is a professional in the field of Information Technology, a Specialist with 10 years of experience leading Business Intelligence and Data Analysis projects with PMP ® certification in Project Management, Microsoft as an Azure Data Engineer, (MCSA) in BI Reporting (Power BI and Excel), (MCSE) in Data Management & Analytics and Data Analyst (Microsoft Data Analyst Associate), Tableau (Desktop Specialist) and with a specialization in Data Science (UNI), in projects in addition to agile frameworks such as Agile Coach (ACPC), Scrum Master (SFPC), Product Owner (SPOPC), DevOps (DEPC) and SAFe (SAFe 5 Agilist). He has experience in financial institutions, consulting firms, statistical areas, and academic institutions, where he has worked in the analysis, exploitation, and automation of information processes. He can be contacted at email: amelendezmu@uni.pe.