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Theory-practice integration: didactic design for teaching energy efficiency

Integración teoría-práctica: diseño didáctico para la enseñanza de la eficiencia energética

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Abstract:

In this research, a didactic design for teaching energy efficiency through Electrical Circuits courses is presented, aiming to link theory with practice using virtual environments and technological tools. The proposal implemented at the Technological University of Havana (CUJAE) seeks to improve the teaching-learning process and develop professional skills in students. It focuses on the study of power, energy, and power factor in three-phase circuits, topics that are traditionally taught theoretically in ideal circuits. A mixed methodology was applied, combining theoretical and empirical methods, which allowed for the definition of methodological guidelines for designing virtual laboratory practices, in addition to using simulation as a method through an application developed in Scilab for load arrangement in industrial systems. The proposal was carried out over three academic courses with a total of 190 students. Methodological meetings were also held to define theoretical-practical exercises and methodological orientations for their execution. Among the main conclusions, it can be mentioned that the proposed didactic design proved effective in improving the teaching-learning process of electrical circuits, linking theory with practice by integrating ICT into the organizational forms of the teaching-learning process. The simulation in Scilab and the problem-based approach fostered active, collaborative, and professionalized learning, preparing students to face real cases in the context of energy efficiency.

Keywords: laboratory practices; teaching-learning process theory-practice relationship; virtual environments; ICT.

Resumen:

En esta investigación se presenta un diseño didáctico para la enseñanza de la eficiencia energética desde las asignaturas de Circuitos Eléctricos, con el objetivo de vincular la teoría con la práctica mediante el uso de entornos virtuales y herramientas tecnológicas. La propuesta implementada en la Universidad Tecnológica de La Habana (CUJAE) busca mejorar el proceso de enseñanza-aprendizaje y formar habilidades profesionales en los estudiantes. Se centra en el estudio de las potencias, energía y el factor de potencia en circuitos trifásicos, contenidos que tradicionalmente se imparten de manera teórica en circuitos ideales. Se aplicó una metodología mixta que *combinó métodos teóricos y empíricos. Lo que permitió definir las pautas metodológicas para el diseño de prácticas de laboratorio virtuales, además del empleo de la simulación como método mediante una aplicación desarrollada en Scilab para el acomodo de cargas en sistemas industriales. La propuesta se llevó a cabo en tres cursos académicos con un total de 190 estudiantes. También, se realizaron reuniones metodológicas para definir ejercicios teórico-prácticos y orientaciones metodológicas para su ejecución. Dentro de las principales conclusiones se puede mencionar que el diseño didáctico propuesto demostró ser efectivo para mejorar el proceso de enseñanza-aprendizaje de los circuitos eléctricos, vinculando la teoría con la práctica a partir de integrar las TIC en las formas organizativas del proceso de enseñanza-aprendizaje. La simulación en Scilab y el enfoque basado en problemas fomentaron un aprendizaje activo, colaborativo y profesionalizado, preparando a los estudiantes para enfrentar casos reales en el contexto de la eficiencia energética.*

Palabras claves: *prácticas de laboratorios; proceso de enseñanza–aprendizaje; relación teoría-práctica; entornos virtuales; TIC.*

Introduction

Currently, Information and Communication Technologies (ICT) play a fundamental role as mediators in the coordination and cooperation relationships established between the teacher, the content, and the students, significantly contributing to the improvement of the teaching-learning process.

In this regard, Capote et al. (2019); Alcivar and Zambrano (2021); Toma et al. (2023); Sultana and Hasan (2023) assert that the obsolescence of knowledge is increasing more rapidly as a result, among other factors, of the dizzying technological progress, which underscores the need for students to develop skills that allow them to enhance their autonomy in their training process and, in turn, feel motivated to acquire and continuously develop new knowledge. Therefore, it is essential to promote the use of ICT in the teaching-learning process to achieve significant transformations in learning.

The integration of ICT in the educational field, as stated by Turgut and Aslan (2021); Alenezi et al. (2023); Abedi (2024), enriches the teaching-learning process by creating virtual environments that optimize communication, understanding of the problem under study, new concepts and knowledge, as well as the autonomous, collaborative, and professionalized learning needs of students, transforming the role of ICT as educational resources. In this context, the adoption of ICT in education has gained relevance and has evolved significantly in recent years, shifting from being an option to becoming an essential didactic tool for improving the quality of the teaching-learning process.

Consequently, based on the above, Quintero et al. (2015); Rodríguez and Gallardo (2020); Medina et al. (2023); Zavala Oscco (2024) argue that in the context of using ICT in the educational environment, the concept of Learning and Knowledge Technologies (TAC) and Technologies for Empowerment and Participation (TEP) emerges, aiming to direct them towards the training, collaboration, and professionalization of the teaching-learning process for both students and teachers. Since ICT contributes to the formative, collaborative, and professional development of students, it is precisely the teacher's role to redirect them towards a focus on TAC and TEP, to foster autonomous, formative, collaborative, and professionalized learning in students.

Therefore, as proposed by Akram et al. (2022), it is fundamental to coherently carry out the integration of ICT - TAC - TEP in the teaching-learning process of any subject, considering the most relevant concepts according to their hierarchy, the level of complexity of the addressed content, the aspects in which students face the greatest difficulties, and the interdisciplinary connections between the different subjects in the curriculum, which must be identified through the analysis of common content. In relation to this, it is important to highlight that the study of engineering is characterized by its primarily interdisciplinary nature, as technological research does not belong exclusively to a specific discipline but requires collaboration from various areas that comprise the engineering in question, allowing for a more thorough and robust analysis of the problems to be solved through their respective theoretical and methodological approaches.

Now, within the objectives of the Electrical Circuits courses, the study of power in three-phase circuits connected in delta and wye, balanced and unbalanced, the relationship established between powers through the power triangle and the power factor, as well as the laws and principles of electrical energy conservation, are included. It is important to note that currently, these contents are taught theoretically in ideal or less complex circuits.

On the other hand, as Carr and Thomson (2022) state, it is important to highlight that electrical energy losses are common and inherent to electric companies and become a serious problem when they exceed certain logical and pre-established limits. These increase the total electricity generation consumption, thus requiring more generation, with the consequent loss of energy resources. Energy losses are an indicator of the efficiency of any electro-energy system.

Overall, in Cuba, Pérez et al. (2024) assert that losses in transmission and distribution systems represent 14,45% of the total electrical energy produced. Typically, losses are approximately 3,5% in the transmission system and 10,95% in the sub-transmission and distribution system. These electrical losses vary according to the network configuration, determined by the location and production of generators, as well as the location and demand of customers. Electrical energy losses during periods of high demand or in overloaded lines tend to be much higher than under lower load conditions. This is because there is a quadratic relationship between electrical losses and the current flow in the line.

For this reason, in the authors' view, it is important for electrical engineering students to acquire the necessary skills from the teaching-learning process of Electrical Circuits courses to carry out the design, operation, maintenance, and improvement of energy efficiency in power electrical systems.

In this sense, the objective is to propose a didactic design for teaching energy efficiency, mediated by virtual environments, to improve the teaching-learning process of Electrical Circuits courses, specifically in the analysis of power in industrial systems. At the same time, it seeks to foster in students the ability to develop innovative solutions in the management, optimization, and energy efficiency of electrical systems.

Materials and methods

Given the importance of implementing a professionalized teaching-learning process in Electrical Circuits courses, and in line with the research objective, it was necessary to review existing theoretical studies and explore the accumulated scientific knowledge on the development, evolution, and improvement of this process in the field of engineering, specifically in electrical circuit theory. This will enhance the teaching-learning process, aligning it with the particularities of the new curriculum and adopting a self-regulated, personalized, and professionalized approach, mediated by virtual teaching-learning environments, through case studies and a problem-based approach.

For this purpose, studies were synthesized using scientific methods, which allowed for the revelation of the essential relationships of the object of study. In the theoretical realm, the historical-logical, analytical-synthetic, inductive-deductive methods, and systematization were employed.

The historical-logical method was fundamental for understanding the references and contexts related to the development and evolution of the teaching-learning process in Electrical Circuits courses. Through this approach, the changes in methodologies and pedagogical approaches over time were analyzed, as well as how these changes have influenced the training of electrical engineers. Additionally, the importance of studying electrical circuits as an essential technical component that forms the basis of the knowledge necessary to face current challenges in the field of electrical engineering was highlighted. This understanding allows for an appreciation of the relevance of a solid education in electrical circuits, which prepares students for professional practice and fosters critical thinking and innovation in a constantly evolving technological environment.

The analytical-synthetic method facilitated a deep analysis of the theoretical positions related to the teaching-learning process. This approach allowed for the identification of regularities and general characteristics of the process, as well as deriving relevant conclusions from new perspectives on professionalization. Thus, a more comprehensive understanding of how current curricular transformations impact student training was achieved, promoting a more adapted approach to the needs of the contemporary educational context.

The inductive-deductive method allowed for the organization of scientific knowledge, focused on studying the factors that influence the teaching-learning process of electrical circuits, and determined the necessary elements to develop the proposed methodological guidelines.

Systematization, as a method, was used to study theoretical references related to the teaching-learning process, in order to define the theoretical position in the design of laboratory practices mediated by virtual environments. This approach seeks to improve the understanding of electrical circuits, especially in the analysis of power in industrial systems, while simultaneously fostering in students the ability to develop innovative solutions in the management and energy efficiency of electrical systems.

As empirical methods, simulation was used to develop the proposed professionalized case study, utilizing the Scilab application proposed by Pérez et al. (2024). Additionally, structured interviews were conducted to gather students' opinions on the usefulness of the proposed laboratory practices, focused on improving the teaching-learning process in Electrical Circuits courses, specifically in the analysis of power in industrial electrical systems and in optimizing the power factor by arranging loads and including photovoltaic solar generation. The sample consisted of students from three consecutive courses (2022, 2023, and 2024) with samples of 50, 70, and 70 students respectively, representing 83%, 100%, and 100% of those who took the Electrical Circuits courses. Statistical methods involved calculating absolute and relative frequencies for processing and analyzing the information obtained from the interviews conducted.

Furthermore, several methodological meetings were held among the professors of the Electrical Circuits courses, where they agreed to determine and approve the professionalized theoretical-practical exercises to be developed using Scilab software, based on the proposed case study, as well as the methodological guidelines for their execution. The methodological procedure for the proposed didactic design, "Power and Factor of Electrical Circuits," is structured around the selection of a case study, chosen according to the course objectives and the connection between the university, industry, and the community. This design is developed through four key components: an introductory lecture, a lecture applying the Problem-Based Learning method, a practical class, and a virtual laboratory exercise, all aimed at fostering active and contextualized learning in electrical engineering.

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Results and discussion

Presentation of the application developed in Scilab

The application "Load Arrangement in Industrial Systems," in its first version, was developed by Pérez et al. (2024) with the aim of providing a working tool for electrical engineers in industries, allowing them to arrange loads effectively.

In Figure 1, the graphical interface of the application is displayed, featuring a column with the hours of the day, while the other two columns correspond to the data of the entity.

It should be noted that the application shows a default set of data, which can be edited according to the analysis of the industrial electrical system for which the load arrangement will be performed. These data include:

- P(kW): Power in kW that must be recorded during each hour of the day at the industrial system's meter or through the installation of a network analyzer.
- fp(pu): The power factor recorded in each measurement.

Additionally, the application allows for the analysis of load arrangement with or without the incorporation of a photovoltaic system. It also provides the option to arrange loads based on a minimum load factor selected by the user. It is important to note that due to the context of the students, the interface of the application is developed in Spanish

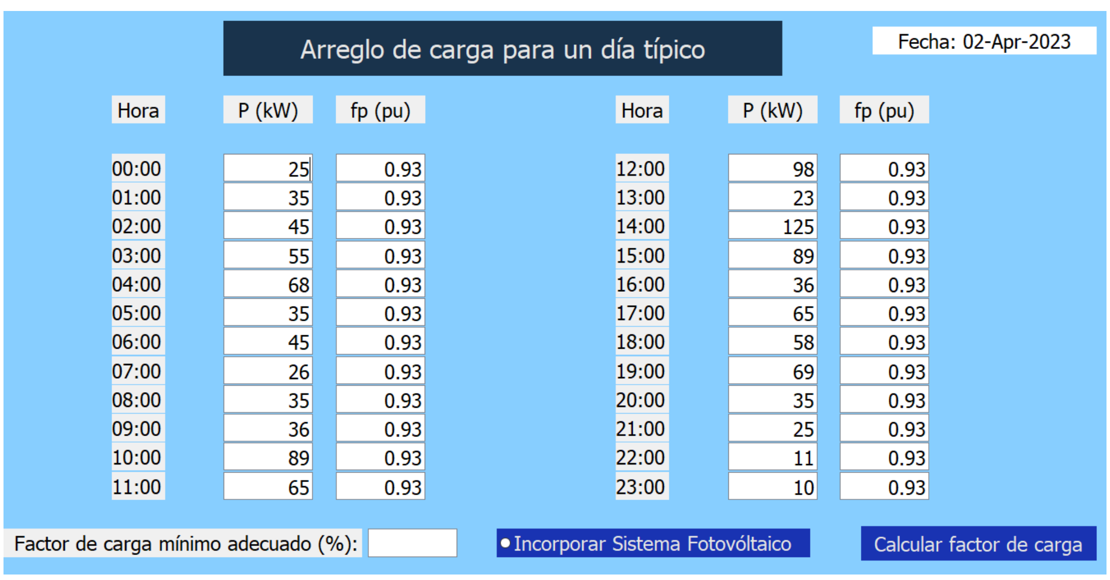

Figure 1. Graphical interface of the load arrangement in industrial systems application. Source: Own elaboration

Once the data of the industrial system has been updated, the engineer must press the "Calculate Load Factor" button, displaying the window shown in Figure 2. In this window, the application shows the calculation of the current load factor of the industrial system and informs the user whether the load needs to be arranged or not, allowing for the selection of the time at which the load arrangement will take place.

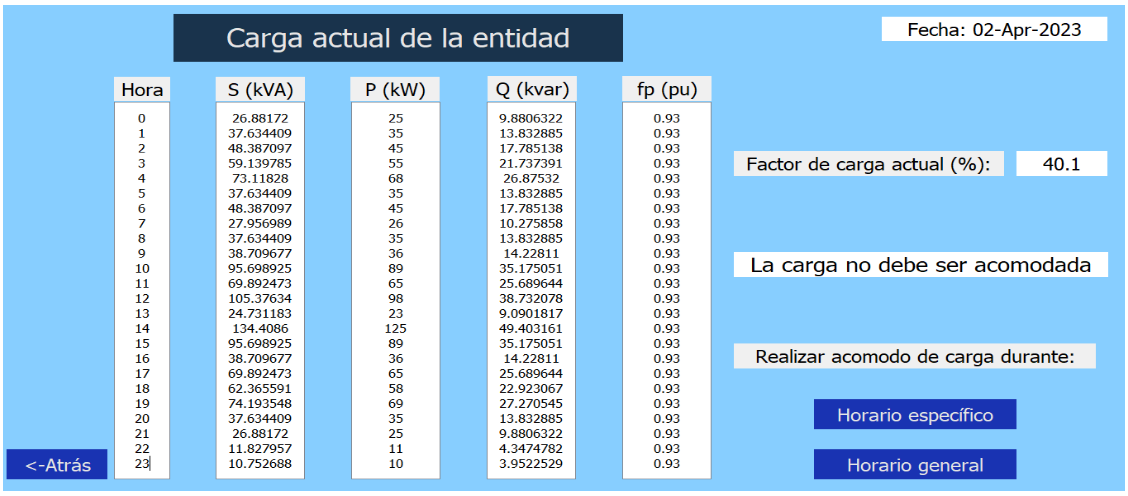

Figure 2. Graphical interface of the load arrangement in industrial systems application with demand factor calculation. Source: Own elaboration

If the user chooses to arrange loads at a specific time, which may be the working hours of the entity where the study is conducted or the predefined peak electrical hours set by the power electrical system, they will be redirected to the screen shown in Figure 3.

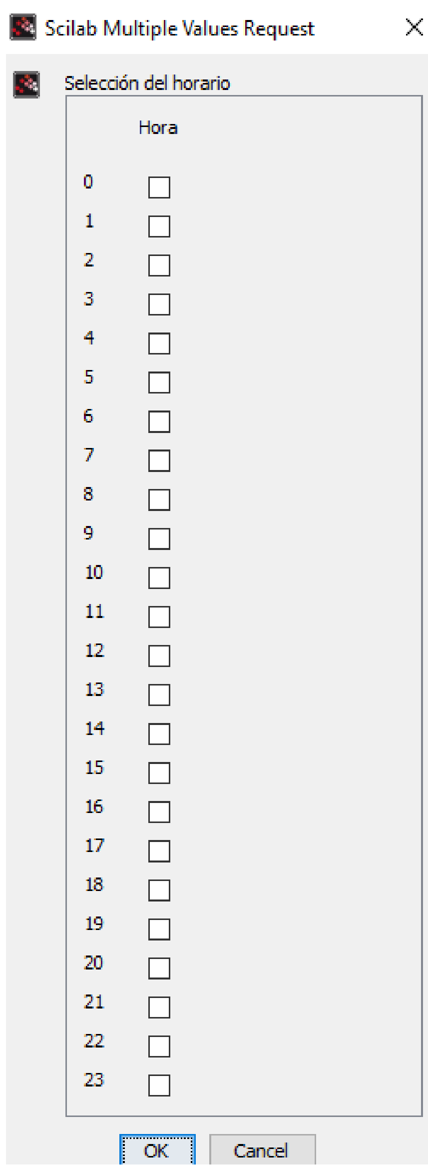

Figure 3. Graphical Interface of the Load Arrangement in Industrial Systems Application for Selecting the Time for Load Arrangement. Source: Own elaboration

It is important to note, as a summary, that among the practical capabilities presented by the application are:

- It arranges loads based on the daily load curve, allowing the user to select the time at which they want the load arrangement to be performed.

- Once the load arrangement is completed, it displays the daily load curve before and after the arrangement.
- It provides the option to conduct the same study, but now with the inclusion of photovoltaic solar panels.
- Based on the billing studies conducted by Pérez et al. (2021), the application suggests whether the maximum demand should be contracted or not after the study is completed and provides a value for its recontracting.
- Additionally, it performs a savings analysis regarding electricity billing after the load arrangement has been completed.

Selection of the case study

As a result of the methodological meetings held, the selected case study to develop the didactic design that allows the study of energy efficiency from the Electrical Circuits courses is the industrial system of UEB Pinturas Vitral, located in the municipality of San José de las Lajas, Mayabeque province. This facility operates with two work shifts: a 24-hour shift for the resin and varnish plant and another 8-hour shift for the painting plant. Data shown in Table #1 was obtained from the installation of a network analyzer.

Item	Value	Unit of Measure
Total Active Power	331,81	kW
Total Reactive Power	210,68	kvar
Apparent Power	355,96	kVA
Power Factor	0,93	-
Connected Load	524,72	kW
Capacitor Bank	81,80	kvar
Maximum Demand	252	kW
Load Factor	37,74	%

Table 1. General data of the UEB. Source: Own elaboration

The daily load curve was also obtained before performing the load arrangement. The curve shown in Figure 4 indicates that the maximum demand occurs at 11:00 AM.

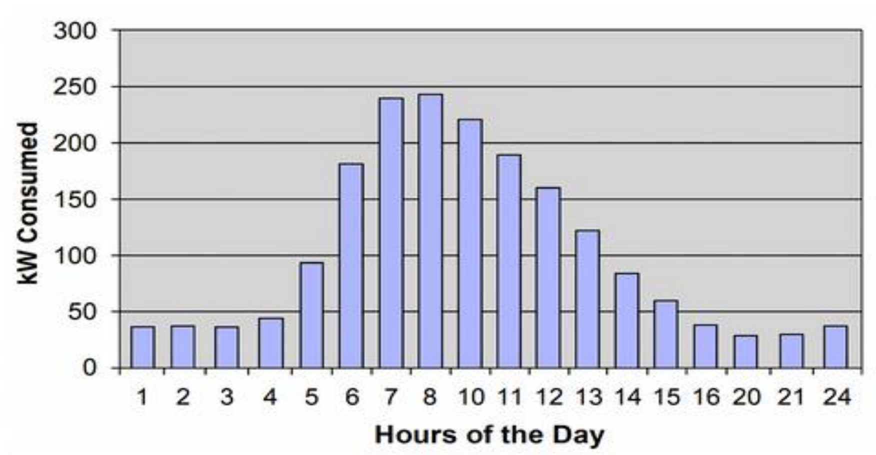

Figure 5. Daily load curve of UEB before load arrangement. Source: Own elaboration

To integrate these contents into the Electrical Circuits courses, the organizational forms of the teaching-learning process mentioned in the Materials and Methods section were utilized. These forms facilitate autonomous,

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collaborative, active, and professionalized learning, as well as the practical application of concepts. The proposed didactic design is as follows:

Conference

Title: Analysis of power calculation in electrical circuits. Power balance. Improvement of power factor.

Objectives:

- Analyze the calculation of power in electrical circuits with alternating current and direct current stimuli.
- Verify the law of conservation of energy through power balance in electrical circuits.
- Explain the methodology to improve the power factor in electrical circuits.

Methodological guidelines

This activity will begin by explaining to the students the concept of electrical power based on the relationship between current, voltage, and impedance. This relationship will be exemplified by constructing a simple circuit with a direct current source, a resistor, and an ammeter to measure the current. The resistance will be varied, and the class will analyze how the current value changes with variations in resistance and its effect on electrical power. The same procedure will then be repeated, but this time replacing the direct current source with an alternating current source. Once the students have understood the concept of power, they can proceed to analyze the operational cost of electrical devices in homes, schools, and offices. Knowing the energy consumption of each electrical device in terms of power allows for more efficient energy management, which can result in significant reductions in electricity expenses. This information is especially relevant in the context of rising energy prices and increasing environmental awareness. For example, if a device consumes 1000 W, it consumes 1 kWh of electrical energy for every hour of operation; these concepts must be made very clear.

Furthermore, it is important to emphasize that the study of electrical power is crucial in engineering and industry, where large amounts of energy are used and/or consumed. For instance, power plants generate megawatts of power to supply electricity to entire cities. Efficiency in generation, transmission, and distribution for energy use is a constant challenge, and understanding electrical power plays a vital role in optimizing these systems.

On the other hand, this activity should explain the concept of the Joule effect and its relationship with energy efficiency. It should be highlighted that this effect, also known as heat due to electric current, is a direct consequence of resistance in a circuit. This phenomenon is fundamental in applications that seek heating, such as ovens, electric showers, and irons.

However, the heat generated by the Joule effect is not always desired. Often, it is a waste of energy, which leads to the importance of energy efficiency. Devices that minimize the Joule effect and convert more electrical energy into useful work are considered more efficient. For example, LED lamps are more efficient than incandescent lamps because they produce less heat in relation to the light emitted.

Understanding the Joule effect and energy efficiency enables engineers and consumers to make informed decisions about the design and use of electrical devices. This not only reduces environmental impact but can also result in significant long-term cost savings.

Additionally, as part of the study of power in electrical circuits, the concepts of apparent power, reactive power, complex apparent power, and the relationship between them should be explained through the power triangle and the power factor as an indicator of energy efficiency quality, along with the most commonly used techniques for its improvement.

It is important for students to understand that improving the power factor and energy efficiency not only has direct economic benefits for users but also contributes to environmental sustainability and the stability of the electrical system. Taking measures to optimize these aspects is essential in a world facing increasing energy and environmental challenges.

In this regard, the most relevant aspects are detailed:

- Reduction of energy costs

Savings on Electricity Bills: An improved power factor reduces the amount of reactive power in the system, which can lower electricity rates, as many utility companies penalize users with a low power factor.

Lower Load on Equipment: By optimizing energy use, the load on transformers and other electrical equipment is reduced, which can result in lower maintenance and replacement costs.

- Efficiency in resource use

Maximization of Capacity: Improving the power factor allows for more efficient use of the installed capacity of electrical systems, meaning more can be done with the same infrastructure.

Reduction of Energy Losses: A higher power factor implies less energy loss in the form of heat in conductors and equipment, contributing to more efficient energy use.

- Environmental impact

Decrease in Carbon Footprint: By improving energy efficiency, the demand for energy is reduced, which can lead to a decrease in electricity generation from non-renewable sources, thus contributing to the reduction of greenhouse gas emissions.

Promotion of Renewable Energy: A better power factor and energy efficiency facilitate the integration of renewable energy sources into the electrical grid, as less backup energy is required.

- Improvement of power supply quality

System Stability: An adequate power factor contributes to the stability of the electrical system, reducing issues such as voltage drops and fluctuations in power quality.

Lower Risk of Overloads: By optimizing energy use, the risk of overloads on electrical equipment is minimized, which can prolong their lifespan and improve system reliability.

- Regulatory compliance

Regulations and Standards: There are regulations that require a minimum power factor for industrial and commercial users. Improving the power factor helps comply with these regulations and avoids penalties.

- Awareness and social responsibility

Education and Environmental Awareness: Promoting the improvement of the power factor and energy efficiency helps create a culture of environmental responsibility among users, encouraging sustainable practices in energy consumption.

In this activity, investigative tasks are proposed, such as:

- Analyzing energy efficiency in lamps

Research and compare the energy efficiencies of an incandescent lamp, a fluorescent lamp, and an LED lamp. Use power and brightness as indicators and prepare a report on how energy efficiency is reflected in the different types of lamps.

• Calculation of operating costs

Select three devices in your home (for example, a hairdryer, a lamp, and a television) and note the nominal power of each. Calculate how much it costs to operate each of these devices for one hour if the electricity price is $0,50 per kWh.

Conference applying the problem-based learning method

Title: Active learning in electrical circuits: applying the problem-based learning method in power calculations, power factor improvement, and energy efficiency.

Objectives:

- Present the problem-based learning method as an effective teaching strategy to enhance the teaching-learning process of electrical circuits.
- Encourage active student participation in solving real professional problems related to power calculations, methods for improving power factor, and energy efficiency.
- Promote collaboration and teamwork among the teacher, students, and groups.

Methodological guidelines

This activity will begin with the contextualization of a real professional problem related to power calculations, power factor improvement, and energy efficiency in a specific environment. To foster collaborative work and autonomous learning, the group will be divided into subgroups of four or five members.

Problem statement:

The “Green Energy” Secondary School has noticed a significant increase in its electricity bills over the past few months. After an initial review, it has been determined that the power factor of the installation is low, contributing to additional costs. The school administration has decided to seek solutions to improve energy efficiency and reduce operating expenses. How can the “Green Energy” Secondary School improve its power factor and optimize its energy consumption to reduce electricity costs?

Provided data:

Current electrical consumption:

Active Power (P): 30 kW

Reactive Power (Q): 20 kVAR

Apparent Power (S): 36,06 kVA

Current Power Factor: 0,83

Costs:

Cost per kWh: $0,15

Penalty for low power factor: $0,05 per reactive kVAR per month.

Electrical Equipment:

Lighting equipment, computers, air conditioning, and other electrical devices.

Tasks for the teams:

Problem analysis:

- Calculate the current cost of electricity based on active consumption and penalties for the power factor.
- Identify the equipment that most contributes to energy consumption and the low power factor.

Improvement proposals:

- Research and propose solutions to improve the power factor to 0.96, such as the installation of capacitors and optimization of equipment use.
- Estimate the implementation cost of the proposed solutions and the potential savings on electricity bills.

Presentation of solutions:

- Each group must present its analysis, proposed solutions, and expected benefits, including an estimated calculation of cost savings.

It is important to highlight that the solutions created must demonstrate how their proposals not only improve the power factor but also contribute to sustainability and the reduction of the school's operating costs. Additionally, the teacher should guide and encourage discussion on the importance of energy efficiency and the environmental impact of the decisions made.

This problem example allows students to apply theoretical concepts to a practical situation, fostering active learning and collaboration. By the end of the activity, students will not only have improved their understanding of power calculations and methodologies for improving power factor but will also have developed problem-solving and teamwork skills.

In this activity, investigative tasks are proposed, such as:

- Researching the concept of daily load chronology curve.
- Understanding the concept of load factor.
- Exploring how photovoltaic solar generation contributes to improving energy efficiency in industrial systems.
- Studying the arrangement of loads in industrial systems.

Practical class

Title**:** Exercises on power calculations, power factor improvement in electrical circuits

Objectives:

- Practice power calculations, power triangles, and power balance in electrical circuits.
- Explain through a practical example what the daily load chronology curve is, how it is constructed, and how to interpret and calculate the load factor.
- Explain what load arrangement means in industrial systems.
- Present the case study for resolution in the virtual laboratory based on the application of electrical load arrangement developed in Scilab.

Methodological guidelines

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In this practical class activity, students will develop professional skills by resolving and studying real case problems related to power calculations in electrical circuits, building on the theoretical and professional knowledge acquired from previous lectures.

This activity will explain, through a professional practical example, what the daily load chronology curve consists of, as well as the calculation and interpretation of the load factor and the arrangement of electrical loads in industrial systems.

Additionally, the presentation of the graphical interface application for electrical load arrangement developed in Scilab will be conducted, along with the case study intended for development in the virtual laboratory activity.

It is important to highlight that during the development of this activity, both oral and written evaluations of the content taught will be conducted.

Research tasks:

- Using the energy measurement device in your home (smart meter), construct the daily load chronology curve and determine the maximum demand.
- Estimate the load factor of your home.

Virtual laboratory practices

Title: Optimization of Electrical Load in an Industrial System Using the Load Arrangement Application Developed in Scilab.

Objective:

- Analyze the effect of load arrangement on the load factor and maximum demand in an industrial system.
- Analyze the integration of photovoltaic solar energy into the system.

Methodological procedure

Based on the selection of the case study, students will use the load arrangement application developed in Scilab to conduct experiments on load arrangement in the industrial system. They will focus on four variants of load arrangement, evaluating their effects on maximum demand and load factor, assuming a minimum adequate load factor of 50% for all variants. The variants are as follows:

- Variant #1: Considering only the peak hours from 11:00 AM to 1:00 PM.
- Variant #2: Considering the peak hours from 6:00 PM to 10:00 PM.
- Variant #3: Considering 24 hours a day.
- Variant #4: Considering 24 hours a day, but now with the integration of photovoltaic generation.

It is important to note that for the development of the virtual laboratory practice, the student groups formed during the lecture activity using the problem-based learning method will be maintained. Additionally, it is essential that during the description and guidance of the laboratory practice, the concepts of maximum demand, load factor, and their importance in the management of electrical systems are revisited and explained.

The peak demand schedules of the Cuban Electroenergy System should be presented, and discussions should be held on how they affect load planning, as well as the importance of integrating renewable energy sources into industrial systems.

The laboratory report will be submitted by the teams on the date set by the course instructor. It should follow the following format:

- Presentation format:
  - Include the name of the subject, title, names of participants, list number, group of participants, and date.
- Introduction:
  - Scientific Problem: Clearly state the scientific problem being addressed in the laboratory practice.
  - Hypothesis: Present the hypothesis that will be tested during the experiment.
  - Objectives: Outline the specific objectives of the laboratory practice.
- Development:
  - Include tables and figures to present data and results.

Additionally, the following questions are formulated to assist in the development of the report:

- ✓ What conclusions can be drawn from the comparison of the daily load chronology curve for each of the variants?
- ✓ Which variant is the best from the perspective of maximum demand recontracting, load factor reduction, and billing analysis?
- ✓ How does the integration of renewable energy sources influence energy efficiency, considering the load factor value, maximum demand value, and electricity billing payment?

- Conclusions: These should be coherent with the objectives outlined in the report.
- Bibliography: Include all consulted sources used in the preparation of the report.
- The report must be well-written with correct spelling and grammar, adhering to the standards of the International System of Units (SI).

Analysis of results

To evaluate the proposal, 50, 70, and 70 second-year students from the Electrical Engineering program at the CUJAE were interviewed for three consecutive years: 2022, 2023, and 2024, representing 83%, 100%, and 100% of the enrollment for each year, respectively. The questionnaire that served as a guide for conducting the interviews was structured as follows:

Question No. 1. In your opinion, did the development of the activities help you to reinforce and link the theoretical and practical contents?

The answers to this question are shown in Table 3.

	Frequency			**%**		
	2022	**2023**	**2024**	**2022**	**2023**	**2024**
Yes	50	70	70	100	100	100

No	-	-	-	-	-	-
To some extent	-	-	-	-	-	-
Total	50	70	70	100	100	100

Table 3. Results of Question No. 1. Source: Own elaboration

Analysis and interpretation:

It can be observed that 100% of the students interviewed, in the three courses, consider that completing the proposed activities and the virtual laboratory using the features of the free software Scilab helped them to understand and reinforce the theoretical contents taught in the conferences. Likewise, it helped them to link these contents with the topic of power quality and load management in industrial systems. According to the students themselves, these aspects highly motivated them regarding the electrical engineering career. From these results, it can be inferred that the proposal greatly contributed to the improvement of the teaching–learning process of electrical engineering students, specifically in topics such as energy efficiency based on circuit theory.

Question No. 2. In your opinion, did the development of the virtual laboratory through the proposed application and the case study help you to develop professional skills?

The answers to this question are shown in Table 4.

	Frequency			**%**		
	2022	**2023**	**2024**	**2022**	**2023**	**2024**
Yes	50	70	70	100	100	100
No	-	-	-	-	-	-
To some extent	-	-	-	-	-	-
Total	50	70	70	100	100	100

Table 4. Results of Question No. 2. Source: Own elaboration

Analysis and interpretation:

100% of the students, in the three courses, stated that the development of the virtual laboratory through the proposed application in solving real professional case studies helped them to develop professional skills and to understand the relationship between circuit theory and energy efficiency analysis in industrial systems. It also supported them in interpreting the load management phenomenon, as well as in studying energy efficiency in a visual and real manner. Moreover, experience is gained through simulation since it allows selecting the best alternative from both the technical and economic perspectives.

Question No. 3. In your opinion, did the proposed didactic design for the study of energy efficiency help you to exchange knowledge and skills with your peers?

The answers to this question are shown in Table 5.

	Frequency			**%**		
	2022	**2023**	**2024**	**2022**	**2023**	**2024**
Yes	50	70	70	100	100	100
No	-	-	-	-	-	-
To some extent	-	-	-	-	-	-
Total	50	70	70	100	100	100

Table 5. Results of Question No. 3. Source: Own elaboration

Analysis and interpretation:

100% of the students, across the three courses, emphasized that through the proposed didactic design for studying energy efficiency based on circuit theory and the resolution of real professional case studies, they were able to exchange information in decision-making regarding load management. They were also able to analyze, from both technical and economic perspectives, which was the best alternative, which in turn enhanced debate and teamwork. This result shows that the integration of information and communication technologies (ICT), from the conception of learning and knowledge technologies (LKT) and technologies for empowerment and participation (TEP), into the teaching–learning process through simulation improves students’ collaborative and autonomous learning, especially when applied in problem solving situations related to the profession and supported by theory.

Conclusions

In alignment with the objective of proposing a didactic design for teaching energy efficiency, mediated by virtual environments, aimed at enhancing the teaching-learning process of Electrical Circuits and professionalizing the study of power in industrial systems, a methodological procedure was structured that integrates lectures, practical classes, and virtual labs. The sequence and articulation of these elements are presented.

The evidence of the technological intervention demonstrates that the simulation in Scilab allowed for the operationalization of the case study and experimentation by variants, supported by the developed application (interfaces reported in Figures 2–4) and the technical characterization of the analyzed industrial system (case data reported in Table 1 and the initial daily curve in Figure 5). This supports the feasibility of linking theory and practice in real contexts of energy efficiency.

Regarding the evaluation of the proposal, the descriptive analysis of the structured interviews shows a consistent student appreciation across the three cohorts (2022–2024), where a positive perception is reported in relation to the theory-practice connection, the development of professional skills, and peer exchange, as indicated by the results recorded in Tables 3, 4, and 5.

Overall, the convergence between the methodological organization of the design, the technical and functional evidence of the simulation-based virtual lab (Figures 2–5 and Table 1), and student appreciation (Tables 3–5) supports the notion that the didactic proposal contributes to improving the teaching-learning process in Electrical Circuits through a contextualized theory-practice integration in energy efficiency.

Finally, the incorporation of information and communication technologies (ICT), from the conception of LKT and TEP, into the teaching of energy efficiency through circuit theory is presented as an innovative and replicable approach in other areas of engineering. The combination of simulations with the study of real case studies not only optimizes the teaching–learning process but also strengthens the training of engineers with greater capacity to develop efficient and sustainable solutions in the electrical sector.

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Author contributions

No.	Contribution Role	Author 1	Author 2	Author 3
1	Conceptualization	90%	4%	6%
2	Data curation	70%	10%	20%
3	Formal análisis	70%	5%	25%
4	Investigation	70%	10%	20%
5	Methodology	85%	5%	10%
6	Software	80%	10%	10%
7	Validation	80%	10%	10%
8	Visualization	80%	10%	10%
9	Writing – original draft	70%	10%	40%
10	Writing – review & editing	80%	10%	20%

Statement of originality and conflict of interest

The author(s) declared that the article: Theory-practice integration: didactic design for teaching energy efficiency

- That article is original, derived from research, and is not under consideration for publication in any other journal simultaneously.
- That both the blind peer review process and any possible corrections to the article, which may be required after communicating the appropriate objections to certain relevant aspects of the article, are accepted.
- That in the event the article is accepted, the author(s) will make the necessary corrections within the stipulated time frame.
- That there are no financial commitments or obligations with public or private institutions that could affect the content, results, or conclusions of the present publication.

Below are the names and signatures of the authors, certifying their approval and agreement with the submitted article.

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