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Design and Planning of the Implementation of an Educational Escape Room for Teaching Fundamental Electrical Circuit Analysis

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Abstract. In university-level Electrical Engineering education, establishing a solid foundation in electrical circuit theory is essential. Core subjects such as Electricity and Magnetism and Electrical Systems provide the basis for advanced courses including Electrical Machines, Power System Analysis, Renewable Energy Integration, and Power Quality studies. However, these foundational subjects are often perceived by students as abstract and mathematically demanding. Traditional lecture-based approaches, while necessary, are not always sufficient to foster deep conceptual learning.
In recent years, active learning strategies grounded in gamification have gained increasing attention in higher education. Among them, educational escape rooms have emerged as innovative tools capable of fostering problem-solving skills, collaboration, engagement, and motivation.
This paper presents the conceptual design and planning of an educational escape room aimed at supporting the teaching of fundamental electrical circuit analysis.
Although the escape room has not yet been fully implemented, a rigorous evaluation framework based on a mixed-methods approach is proposed. Preliminary feedback from senior students involved in the pilot testing phase indicates a high level of acceptance and perceived educational value.
The main contribution of this work lies in providing a transferable instructional design framework aligned with the educational interests of the ICREPQ community.

Key words. Electrical engineering education, educational escape rooms, active learning, circuit analysis, gamification.

1. Introduction

Fundamental circuit analysis constitutes a cornerstone of undergraduate Electrical Engineering education. Concepts such as series and parallel associations of passive elements, resonance and Kirchhoff's laws are essential for understanding electrical networks and constitute prerequisites for advanced subjects such as filter design. Despite its importance, extensive teaching experience in first-year courses indicates that many students struggle to develop a solid conceptual understanding of circuit analysis. The abstract nature of the concepts, combined with the level of mathematical formalism required, often encourages surface learning strategies focused on applying formulas rather than conceptual understanding. As a result, students may struggle to transfer their knowledge to new contexts in later courses, which negatively affects their academic progression.
Previous research has shown that students often struggle with the conceptual understanding of electrical circuits, particularly in relation to current flow, voltage distribution, and the application of Kirchhoff's laws [1], [2]. These difficulties are frequently associated with persistent misconceptions that hinder the development of a coherent mental model of circuit behaviour. This reinforces the need for instructional approaches that go beyond procedural problem-solving and promote conceptual understanding.
Recent literature shows that educational escape rooms have been increasingly explored as an active learning strategy in STEM education [3], [4], including software engineering [5], telecommunications [6] and industrial engineering [7]. Systematic reviews indicate that these game-based activities have been applied across science, mathematics, and engineering disciplines, often enhancing engagement, collaboration, and problem-solving skills, though rigorous evidence of learning effectiveness remains limited [8], [9].
Specific applications in engineering education include case studies such as the "Escape Department" [10] escape room for engineering students, which fostered teamwork and interdisciplinary learning, and gamified experiences in control engineering [11].
In addition, randomized trials in software engineering report that escape room-based learning can yield higher knowledge acquisition and positive perceptions compared with traditional lectures [12].
These findings align with research on gamification in engineering, which highlights that game design elements can improve motivation and participation in technical subjects [13].
Nevertheless, a detailed review of the scientific literature reveals a lack of published studies focusing on the use of escape rooms for teaching core electrical engineering concepts such as circuit analysis. This gap motivates the present study.

The main contributions of this work are:

1) The design of a scalable educational escape room adapted to large first-year Electrical Engineering cohorts.
2) The alignment of game-based challenges with core circuit analysis learning objectives.
3) The integration of physical and conceptual tasks to reinforce abstract electrical principles.
4) The proposal of a rigorous evaluation framework combining quantitative and qualitative methods.
5) The development of a transferable instructional model applicable to other engineering domains.

To the best of the authors' knowledge, this is one of the first works specifically addressing the use of educational escape rooms for teaching fundamental circuit analysis in Electrical Engineering.

2. Educational rationale and scope

The proposed educational escape room is designed for first-year undergraduate students enrolled in Electrical Engineering degree programs, typically during their first formal exposure to circuit analysis. The primary objective of the activity is to reinforce core circuit analysis concepts through an active and collaborative learning experience that complements traditional lectures and problem-solving sessions. The scope of the escape room is deliberately focused on fundamental electrical concepts, including series and parallel associations of resistors, capacitors, and inductors, as well as the application of Kirchhoff's current and voltage laws. These topics were selected due to their central role in introductory courses and their direct relevance to later subjects related to power systems, power quality and renewable energy technologies. The proposed design is modular and can be adapted to different contexts, class sizes, and time constraints, making it suitable for a wide range of introductory Electrical Engineering courses.

3. Theoretical background

A. Constructivist learning

Constructivist theory emphasizes that knowledge is actively constructed through interaction with meaningful tasks. In circuit analysis, this implies that students benefit from engaging directly with problem-solving activities rather than passively receiving information.

B. Active learning

Active learning strategies require students to participate in tasks that involve analysis, synthesis, and evaluation.
Research has consistently shown that such approaches improve student performance and retention compared to traditional lectures [14]. The escape room format inherently supports active learning by requiring continuous student participation.

C. Gamification and game-based learning

Gamification incorporates elements such as goals, challenges, feedback, and time constraints to increase motivation and engagement. Educational escape rooms represent a form of game-based learning where students must solve interconnected challenges to achieve a common objective.
The integration of these theoretical perspectives provides a strong pedagogical foundation for the proposed activity.

4. Instructional design of the escape room

A. General organization

The educational escape room is designed as a face-to-face activity integrated into a first-year Electrical Engineering course with typical class sizes ranging around 160 students. Due to the large number of participants, the time limit is approximately 30 minutes. Students work in teams of around five participants, promoting effective peer discussion and collaboration while maintaining individual engagement. Larger groups are considered less suitable, particularly given that during the first two years of the degree, students from specialities such as Electrical, Electronic and Mechanical Engineering work together.

B. Challenges and learning objectives

The challenges are sequentially organized and aligned with specific learning objectives. It starts with basic calculations of series and parallel associations of passive elements and gradually progresses to more complex tasks involving the application of Kirchhoff's laws. Each challenge requires students to analyse circuit schematics, perform calculations, interpret results, and make collective decisions. Successful completion of a challenge provides a clue or code required to unlock the next stage, maintaining engagement and continuity.

C. Escape room structure

The escape room consists of a sequence of challenges organized with increasing complexity. The instructional design follows three main principles:

1) *Alignment:* each challenge is linked to learning objectives.
2) *Progression:* Tasks increase in cognitive complexity.
3) *Feedback:* Immediate validation through codes or clues.

D. Challenge structure

Each challenge within the escape room corresponds to a measurable learning objective, as shown in Table I.
From an electrical engineering perspective, the challenges are designed not only to reinforce procedural calculation skills, but also to promote conceptual understanding of circuit behaviour, including current distribution, voltage drops, and equivalent impedance in complex networks.

Table I. – Mapping of challenges to electrical engineering concepts.

CHALLENGE	CONCEPT TARGETED	MECHANISM
1	Series and parallel resistances association	Students compute equivalent value from given data
2	Series and parallel resistances association in an energized circuit	Students assemble the circuit and measure equivalent values from real elements
3	Inductances association	Students compute equivalent value from given data
4	Capacitors association	Students compute equivalent value from given data
5	Kirchhoff's current law	Physical analogy using a balance scale to represent current conservation
6	Kirchhoff's voltage law	Measurement in real circuit of voltage drops

E. Storytelling

The narrative scenario involves the restoration of a malfunctioning electrical laboratory system before a system shutdown occurs, providing a realistic engineering context. Furthermore, the escape room takes place in the electrical engineering laboratories of the University of La Rioja, which significantly enhances the immersive experience. The storyline is intentionally simple, serving primarily as a contextual framework to support the technical challenges. Figure 1 shows the setting during the escape room activity.

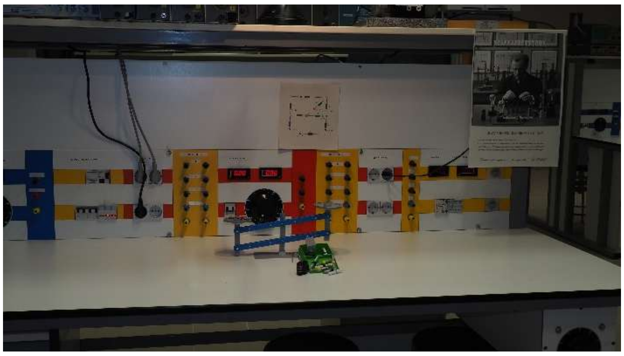

Fig. 1. Setting in which the escape room takes place.

F. Kirchhoff's current law challenge

Kirchhoff's current law (KCL) states that the algebraic sum of currents at a node is zero, meaning that the total current entering a node is equal to the total current leaving it. This principle is a direct consequence of charge conservation and constitutes a fundamental concept in circuit analysis.
In the proposed escape room, KCL is represented through a physical analogy based on a balance scale. The balance, designed using 3D printing technology (Figure 2), allows students to visualize current conservation in an intuitive manner. Each weight represents a current value: currents entering the node are placed on one side of the scale, while currents leaving the node are placed on the opposite side.

Equilibrium of the scale represents the satisfaction of Kirchhoff's current law. Only when students correctly identify the relationship between the currents and achieve balance does the system reveal the code required to proceed to the next challenge.
This tangible representation facilitates the transition from abstract mathematical formulation to conceptual understanding, particularly beneficial for first-year students encountering circuit laws for the first time.
The mathematical expression of KCL is given by (1):

$$\sum I_{in} = \sum I_{out} \tag{1}$$

or equivalently (2):

$$\sum I = 0 \tag{2}$$

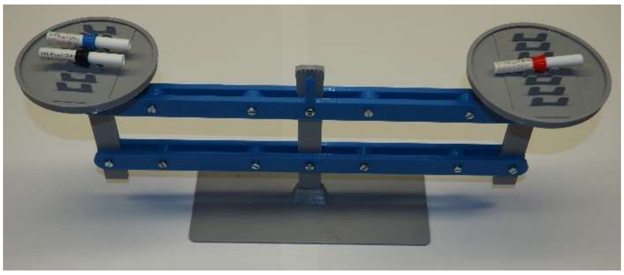

Fig. 2. 3D-printed balance and associated weights used in this challenge.

G. Weaknesses

A potential limitation of the proposed design is the initial preparation effort required from instructors, particularly during the development of the challenges and supporting materials. However, once established, the activity can be reused with minor adaptations in subsequent academic years. For this reason, the escape room is conceived as a flexible instructional framework that can be adjusted in complexity or duration according to institutional constraints and student profiles.

5. Research design and methodology

This study follows a design-based research approach, combining the development of an educational intervention with the design of a framework for its evaluation.

A. Sample

Approximately 160 first-year students enrolled in the Electrical Engineering program will participate in the study. A randomized controlled design will be employed, with students assigned to either an experimental group (escape room-based learning) or a control group (traditional lecture-based instruction). Each group will consist of approximately 80 participants. This design aims to ensure internal validity and enable a robust comparison between instructional approaches.

B. Planned assessment methodology

Although the educational escape room has not yet been fully implemented, a structured assessment methodology

has been designed to evaluate its effectiveness once deployed (Table II). The planned evaluation framework adopts a mixed-methods approach combining quantitative and qualitative data. The quantitative component consists of a pre-activity test assessing students' prior knowledge of fundamental circuit analysis concepts and a post-activity test of comparable difficulty to measure learning gains. The qualitative component includes a student perception survey focusing on engagement, motivation, perceived usefulness of the activity, and teamwork dynamics. This combination is intended to provide a comprehensive view of both learning outcomes and student experience.
The control group will also provide valuable information to the study. The comparison between the control and experimental groups aims to generate evidence to inform the teaching of electricity at the university level. Specifically, the study seeks to determine whether game-based learning approaches, such as an educational escape room, are more effective than traditional instructional methods.

Table II. – Different types of instruments used to collect participants' data.

METRIC	METHOD	PURPOSE
Test score	Pre/Post test	Learning gain
Survey	Likert scale	Engagement, motivation
Learning gains	Control group vs experimental group	Comparison of learning gains

C. *Statistical approach*

The statistical analysis is designed to rigorously evaluate the effect of the educational escape room on students' conceptual understanding and related pedagogical variables within a quasi-experimental framework. The analysis will combine descriptive and inferential techniques.
Cognitive performance will be assessed through pre-test and post-test scores, complemented by the calculation of normalized learning gains to account for differences in prior knowledge. Initial group equivalence will be verified using independent samples tests, while within-group improvements will be examined through paired comparisons. Differences between instructional approaches will be analysed using independent tests and effect size measures, providing both statistical and practical significance.
To control for baseline differences, an analysis of covariance (ANCOVA) will be conducted, incorporating pre-test scores as a covariate. In addition, survey-based variables such as motivation, collaboration, and self-efficacy will be analysed using reliability measures and composite indices.
Relationships between cognitive and non-cognitive variables will be explored through correlation and regression analyses, allowing identification of key predictors of learning outcomes. When appropriate, advanced multivariate techniques may be applied to further examine the underlying structure of these relationships.

6. Conclusions and future perspectives

This work focuses on the design phase, with implementation and validation currently in progress. This paper presents the design and planning of an educational escape room aimed at enhancing the learning of fundamental circuit analysis concepts in undergraduate Electrical Engineering education. The proposed approach integrates active learning, gamification, and collaborative problem-solving within a structured and scalable instructional framework.
The main expected contribution of this activity is the improvement of students' conceptual understanding of circuit analysis, as well as increased engagement and motivation in first-year courses traditionally perceived as challenging. In addition, the proposed design facilitates the development of transversal skills such as teamwork, communication, and problem-solving. Moreover, this work contributes to bridging the gap between abstract circuit theory and experiential learning in Electrical Engineering education.
A key strength of the proposed approach lies in its adaptability to large student cohorts and its potential for reuse with minor modifications, making it a sustainable teaching innovation.
Future work will focus on the full implementation of the escape room and the empirical evaluation of its impact using the proposed mixed-methods framework. The results obtained will provide evidence on the effectiveness of game-based learning strategies in Electrical Engineering education.
Furthermore, the methodology may be extended to more advanced topics, including power systems, renewable energy integration, and power quality, reinforcing its relevance within the ICREPQ community.

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References

[1] P. V. Engelhardt and R. J. Beichner, "Students' understanding of direct current resistive electrical circuits."
[2] D. P. Maloney, T. L. O'Kuma, C. J. Hieggelke, and A. Van Heuvelen, "Surveying students' conceptual knowledge of electricity and magnetism," *Am. J. Phys.*, vol. 69, no. S1, pp. S12–S23, Jul. 2001, doi: 10.1119/1.1371296.
[3] J. L. Gómez-Urquiza, J. Gómez-Salgado, L. Albendín-García, M. Correa-Rodríguez, E. González-Jiménez, and G. A. Cañadas-De la Fuente, "The impact on nursing students' opinions and motivation of using a 'Nursing Escape Room' as a teaching game: A descriptive study," *Nurse Educ. Today*, vol. 72, pp. 73–76, Jan. 2019, doi: 10.1016/j.nedt.2018.10.018.
[4] C. Jiménez Sánchez, R. Lafuente Ureta, M. Ortiz Lucas, L. Bruton, and V. Millán Luna, "Room Escape:

Propuesta de Gamificación en el Grado de Fisioterapia," Universitat Politecnica de Valencia, Jul. 2017. doi: 10.4995/inred2017.2017.6855.
[5] A. Gordillo, D. Lopez-Fernandez, S. López-Pernas, and J. Quemada, "Evaluating an Educational Escape Room Conducted Remotely for Teaching Software Engineering," *IEEE Access*, vol. 8, pp. 225032–225051, 2020, doi: 10.1109/ACCESS.2020.3044380.
[6] S. López-Pernas, A. Gordillo, E. Barra, and J. Quemada, "Examining the Use of an Educational Escape Room for Teaching Programming in a Higher Education Setting," *IEEE Access*, vol. 7, pp. 31723–31737, 2019, doi: 10.1109/ACCESS.2019.2902976.
[7] J. Sánchez-Martín, M. Corrales-Serrano, A. Luque-Sendra, and F. Zamora-Polo, "Exit for success. Gamifying science and technology for university students using escape-room. A preliminary approach," *Heliyon*, vol. 6, no. 7, Jul. 2020, doi: 10.1016/j.heliyon.2020.e04340.
[8] C. Lathwesen and N. Belova, "Escape rooms in stem teaching and learning—prospective field or declining trend? A literature review," *Educ. Sci. (Basel).*, vol. 11, no. 6, Jun. 2021, doi: 10.3390/educsci11060308.
[9] C. Kim, H. Na, N. Zhang, and C. Bai, "Escape Rooms for Education: A Meta-analysis," *International Journal of Instruction*, vol. 17, no. 4, pp. 219–234, Oct. 2024, doi: 10.29333/iji.2024.17413a.
[10] G. Scandurra and C. Ciofi, "Escape Room Game for Engineering Students: 'Escape Department', a Case Study," *Educ. Sci. (Basel).*, vol. 13, no. 8, Aug. 2023, doi: 10.3390/educsci13080785.
[11] J. González-Hernández, F. Cañadas-Aránega, Á. Hoyo, P. Otálora, I. Pataro, and J. D. Gil Vergel, "Escape room en Ingeniería de Control," *Jornadas de Automática*, no. 45, Jul. 2024, doi: 10.17979/ja-cea.2024.45.10794.
[12] A. Gordillo and D. Lopez-Fernandez, "Are Educational Escape Rooms More Effective Than Traditional Lectures for Teaching Software Engineering? A Randomized Controlled Trial," *IEEE Transactions on Education*, vol. 67, no. 5, pp. 660–668, 2024, doi: 10.1109/TE.2024.3403913.
[13] J. Díaz-Ramírez, "Gamification in engineering education – An empirical assessment on learning and game performance," *Heliyon*, vol. 6, no. 9, Sep. 2020, doi: 10.1016/j.heliyon.2020.e04972.
[14] S. Freeman *et al.*, "Active learning increases student performance in science, engineering, and mathematics," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 111, no. 23, pp. 8410–8415, Jun. 2014, doi: 10.1073/pnas.1319030111.