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Effectiveness of extracurricular activities with an interdisciplinary approach and the teaching of digital technologies in Refrigeration

Eficacia de las actividades extraescolares con un enfoque interdisciplinario y la enseñanza de las tecnologías digitales en Refrigeración

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Abstract: This study proposes an innovative model for teaching Mechanical Engineering, centered on extracurricular activities with an interdisciplinary approach and digital technologies in the field of refrigeration. The implemented methodology was based on three fundamental pillars: an educational booklet for calculating thermal loads, specialized software (Solkane, Psychometric Chart C) for simulations, and a redesign of the teacher's role as a facilitator. The activities were organized into three phases: orientation, execution, and control, incorporating formative assessment. The results demonstrated a 40 % reduction in problem-solving time, an 85 % accuracy rate in refrigerant selection (compared to the initial 30 %), and a 90 % correlation between theory and practice. Significantly, 45 % of the students chose refrigeration topics for their thesis projects, demonstrating greater motivation and technical depth. The model proved effective in developing technical skills, autonomy, and critical thinking, overcoming the limitations of traditional hands-on methods. Technical difficulties due to insufficient equipment and time constraints were identified as limitations. The study concludes that integrating pedagogical innovation, technical rigor, and ethical training constitutes an effective paradigm for the education of contemporary engineers. It recommends faculty workshops, continuous access to digital resources, and simulators for remote practice.

Keywords: engineering education, extracurricular activities, refrigeration, active learning methodology

Resumen: El estudio realizado propone un modelo innovador para la enseñanza de la Ingeniería Mecánica centrado en actividades extracurriculares con enfoque interdisciplinario y tecnologías digitales en el ámbito de la refrigeración. La metodología implementada se sustentó en tres pilares fundamentales: un folleto educativo para cálculo de cargas térmicas, software especializado (Solkane, Psychometric Chart C) para simulaciones y el rediseño del rol docente como facilitador. Las actividades se organizaron en tres fases: orientación, ejecución y control, incorporando evaluación formativa. Los resultados demostraron una reducción del 40 % en el tiempo de resolución de problemas, precisión del 85 % en selección de refrigerantes (frente al 30 % inicial) y correlación del 90 % entre teoría y práctica. Significativamente, el 45 % de los estudiantes eligieron temas de refrigeración para sus proyectos de grado, evidenciando mayor motivación y profundidad técnica. El modelo mostró efectividad en el desarrollo de competencias técnicas, autonomía y pensamiento crítico, superando las limitaciones de los métodos reproductivos tradicionales. Se identificaron como limitaciones dificultades técnicas por equipamiento insuficiente y restricciones de tiempo. El estudio concluye que la integración de innovación pedagógica, rigor técnico y formación ética constituye un paradigma efectivo para la formación de ingenieros contemporáneos, recomendándose talleres docentes, acceso permanente a recursos digitales y simuladores para práctica remota.

Palabras clave: educación en ingeniería, actividades extracurriculares, refrigeración, metodología activa

Introduction

Higher education needs a new student-centered model, where extracurricular assignments stimulate research linked to course projects and diploma theses (Garay, 2022), where educational technologies, collaborative work, and problem-based learning are integrated, guaranteeing the resolution of complex challenges with interdisciplinary approaches (Chi Maimó *et al.*, 2011; La O-Sánchez, 2022). Its design is based on two models: the triphasic (Preparation-Execution-Evaluation), effective for techno-complex problems (Sánchez & Ortega, 2022), and the Quadripartite, which prioritizes teacher-student interaction (Benítez Fernández & Fernández García, 2009).

Multidisciplinary projects have strategic value for developing professional competencies, but they require quantitative validation and specific implementation frameworks. The incongruity between academic training and professional practice demands that students understand professional norms, conventions, and language (Johri, 2022; Lowe *et al.*, 2022). Less prescriptive activities, based on real-world problems, facilitate the transition from reproduction to innovation (Asplund & Flening, 2022; Lowe *et al.*, 2022). The proposed cold storage design implements this principle, empirically validating its effectiveness in the comprehensive training of engineers.

Multidisciplinary projects as a strategy facilitate the development of collaboration and complex problem-solving skills in engineering (Ancayay Leal, 2024; Chávez Suárez, 2023; Vergara et al., 2024), although their effectiveness depends on overcoming barriers such as curricular fragmentation. Interdisciplinary interaction fosters systems thinking and a deep understanding of real-world problems (Gil-Vallejo *et al.,* 2018; Vergara *et al.,* 2024). One of the main challenges for its development is the lack of coordination and resources (Rojas Arenas *et al.*, 2020) a limitation that this study empirically corroborates.

Extracurricular assignments, defined as partial assessments that validate thematic and interdisciplinary objectives (Resolution 02/18) (Reglamento de Trabajo Docente y Metodológico de la Educación Superior, 2018), articulate autonomous learning in real professional contexts, develop complex cognitive competencies (critical thinking, creativity) and professional skills (time management, research), while functioning as a bridge between subjects and degree projects. Their effective design requires progressive curricular integration, teacher mastery of digital pedagogies, and the implementation of formative assessment systems (Estrada Molina *et al.*, 2018; Medina-Martínez & Ruíz-García, 2021).

However, extracurricular homework presents barriers such as insufficient technological and pedagogical preparation of teachers and rigid curricular structures, which limit curricular interconnectedness and the effective use of ICTs. Overcoming these barriers requires teacher training programs that transcend the technical, emphasizing problem-based designs and formative assessment (Aguirre-Borja *et al.,* 2015). To achieve this, a scalable design that articulates progressive content and fosters interdisciplinary collaboration is recommended. Its systematic implementation elevates educational quality and strengthens the theoretical-practical relationship through academic training and job demands, where they develop creativity and self-regulation (Zimmerman, 2002). This consolidates extracurricular homework as a tool to train professionals capable of facing contemporary technosocial challenges, combining technical mastery, cognitive autonomy, and collaborative work.

There is a critical disconnect in the development of transversal competencies: although teachers promote them, their omission from curricula and systematic assessment prevents students and industry from recognizing them (Leandro Cruz & Saunders-Smits, 2022). Furthermore, their relevance is contextual—not generic—so they must be explicitly integrated into the curriculum, rigorously assessed, and adapted to specific professional roles (Flening et al., 2022). The study applies this principle through extracurricular tasks that simulate real-world challenges in refrigeration.

Engineering curricula should incorporate progressively complex, clearly presented, and personalized teaching tasks that foster self-learning in four-year curricular programs and blended and distance learning modalities. This ensures an effective transition from actual student development levels to mastery of professional competencies through purposeful and accessible pedagogical strategies.

Interdisciplinarity integrates knowledge across subjects and throughout the degree program through scalable instructional designs and adaptive assessment systems Sánchez & Ortega, 2022). However, curricular fragmentation (subjects not grouped by discipline) and insufficient timetables hinder the achievement of complex objectives. As a solution, extracurricular assignments link basic content (1st to 2nd year) with professional applications (3rd to 4th year), fostering specific technical skills and interdisciplinary competencies. Furthermore, they make up for the limitations of the classroom and compensate for the lack of coordination between subjects with independent work that articulates theory and practice, proving to be essential tools for comprehensive engineering training.

Engineering education requires perfect teaching methods, procedures, and media to ensure educational standards. Although there are precise methodological guidelines for teaching the core content of the subject areas, there are shortcomings in the procedures to be followed to achieve the objectives.

The main methodological shortcomings identified in the teaching of Refrigeration, Air Conditioning, and Ventilation are manifested in: the predominance of reproductive methods (based on repetition), which limit the development of creative skills in students; the lack of integration of digital media (e.g., specialized software such as Solkane) and updated teaching resources; and difficulties in covering the volume of content within the allotted time, which affects the assimilation of key concepts such as thermal load calculation or refrigerant selection. These problems generate a didactic contradiction between "what to teach" (technical content) and "how to teach it" (effective strategies), compromising the comprehensive training of mechanical engineers.

This article aims to guide teachers in the application of innovative methodological procedures for teaching through extracurricular assignments. It is illustrated by the experience developed and results achieved in the field of refrigeration, through the implementation of productive methods, the integration of technological tools, and the redefinition of the teacher's role as a facilitator (rather than a traditional lecturer). The aim is to ensure that students acquire technical skills and professional values aligned with the demands of the industrial sector.

Development

The pedagogical transformation in the teaching of Refrigeration within the Refrigeration, Air Conditioning and Ventilation (RCV) subject proposes a significant evolution from traditional reproductive teaching models toward productive approaches centered on active learning. This paradigm shift is based on three fundamental pillars that integrate innovative teaching resources.

The first strategic component consists of the development of an educational booklet for calculating refrigeration thermal loads. This booklet is designed to foster independent learning, both in-person and through independent work, always with instructor supervision and validation. This material includes detailed protocols for determining the dimensions of cold storage chambers, preservation techniques, and criteria for optimal diffuser positioning. Complementing the theory, the booklet includes practical exercises based on real-life industrial cases, such as the analysis of thermal losses in different facilities.

The second methodological focus is the systematic integration of specialized software into the teaching-learning process. Among the selected tools are Solkane and Ref94 for refrigeration cycle simulation and refrigerant selection, Psychometric Chart C for the analysis of thermodynamic properties, and specific applications for the automated calculation of thermal loads in cold storage chambers. These technological tools are incorporated through practical workshops where students compare manually obtained results with those generated digitally, in addition to analyzing complex industrial cases that consider energy and environmental variables.

Integrating sustainability and ethics into engineering education is a curricular imperative. Although early-career engineers understand global responsibility, their ability to apply it is limited by organizational barriers, requiring greater institutional support (Chance *et al.*, 2022). Early-career female engineers place greater value on social and sustainability aspects, suggesting that their potential in this area may be undervalued (Naukkarinen & Bairoh, 2022). These findings emphasize the need for an education that fosters professional agency to overcome practical limitations and lead the transition to responsible engineering. Education should not be limited to teaching technical and environmental criteria (such as the selection of low-GWP refrigerants); it must explicitly foster professional agency so that graduates can transcend practical constraints and lead the transition to truly responsible engineering—a central objective of the didactic approach proposed here.

Formal education, while necessary, is often insufficient to develop the skills required in practice. For this reason, integrating technology into engineering education transcends the instrumental view of software as a mere tool. Informal learning through participation in online platforms and scientific networks is fundamental for developing students' professional identity and competence (Johri, 2022). This contribution validates and enriches the implementation of specialized software (Solkane, Psychometric Chart C) in the proposed model, demonstrating that its use not only optimizes calculations but, when contextualized in authentic tasks, functions as a vehicle for active learning. Technical and professional mastery is fostered, something conventional instruction alone does not guarantee, preparing students for the collaborative digital ecosystems of modern industry.

The third transformative component involves a redefinition of the teaching role, shifting from a traditional expository model to a learning facilitation approach. In this new paradigm, the teacher guides the educational process through carefully designed problem-solving questions that stimulate critical thinking. In addition, collaborative learning strategies are implemented through group work geared toward the design of technical solutions. The evaluation system is enriched using specific rubrics that assess not only computational skills but also the ability to select teams and sound technical argumentation.

This three-pronged methodological strategy (specialized teaching materials, technological integration, and a new teaching role) forms a coherent system that seeks to develop comprehensive professional skills in mechanical engineering students, preparing them for the real challenges of professional practice in the field of refrigeration.

Extracurricular homework is implemented as a teaching strategy to reinforce independent learning, systematize content, and assess student mastery through a theoretical and practical approach adapted to the educational context. Its design includes clear objectives, relevant content (knowledge, skills, and values), and structured activities with bibliographic sources. The process was organized into three phases: orientation (understanding and motivation), execution (research, information processing, and report preparation), and monitoring (formative assessment through written work and presentations). The planning prioritized clear communication, systematic follow-up, and attention to individual differences, ensuring effective feedback (Álvarez de Zayas, 1999).

The main variable measured was the level of assimilation achieved by students in the Refrigeration Topic 1 content of the RCV course. This constituted an indicator of the effectiveness of the teaching tasks implemented to achieve mastery of the subject content. Measurements of this variable were carried out in the first midterm assessment project, in the defense of the extracurricular homework activity, and the final exam activity, using similar assessment instruments (similar difficulty and discrimination indices; data not shown). The assessments reflected the degree of mastery of the subject content for each student. The instrument consisted of items that required different levels of content mastery. Based on the students' responses, the level of assimilation achieved was classified as: familiarization, reproduction, production, and creation.

Characteristics of the Extra-Class assignment

In task design extra-class six didactic principles are included: educational (reflects student responsibility during its execution), scientific (implicit in its objectives and contents), accessibility (adaptation to the student's level), systematization (progressive organization), theory-practice link (contextualized application) and solidity in assimilation (evidenced through oral discussions), which strengthen both autonomous learning and meaningful mastery of the contents and define the actions to achieve the evaluative objectives. They are presented with a systemic approach, linked to the professional profile through real situations, structured as contextualized problems that require the use of professional software for their resolution, culminating in the preparation of reports submitted for discussion. The use of real data reinforces its practical nature and increases motivation by facilitating significant connections with authentic professional situations (Álvarez de Zayas, 1999).

The designed problems integrate the discipline's content, act as a research tool, and demonstrate the cross-disciplinary applicability of the acquired knowledge and its impact on the graduate's profile. Furthermore, students are considered professionals in training and focus on developing key competencies: appropriate selection of methods, database construction, use of professional software, interpretation of results, and drawing valid conclusions.

The task tracking process for Extracurricular activities includes systematic in-person assessments where the teacher monitors student progress and makes pedagogical adjustments. At the same time, through lectures and practical classes, students acquire the skills necessary to meet the learning objectives.

A task is developed extra-class assignment for each topic of the subject, aimed at the beginning of the course and delivered one week after completing the contents. The oral discussion takes place in a workshop where skills are assessed through questions based on the tasks performed. The group debate allows for general conclusions to be reached about the work done. Extracurricular activities promote the proper balance between individual and group work and facilitate the development of emotional intelligence towards the task of studying.

Example of extra-class work

The extracurricular assignment integrates content from the program and year-round courses. All students are presented with the same problem statement to solve, but each one is given a different product to preserve or freeze. They can also choose the product if they are involved in any research related to the topic.

Example:

A client approaches the project company where you work as a Refrigeration Engineer and requests the design of a commercial cold storage facility to preserve a specific product. Based on this request, the final-year Mechanical Engineering student should be able to complete the task.

To do this, the teacher writes instructions in a document that serves as a guide for the student.

Directions for extra-class homework

Topic 1: Refrigeration

General Instructions: Select the compressor, condenser, and evaporator for the installation.

Specific Instructional Objectives:

- Determine the cooling thermal load for a commercial cold room.
- Select the ideal type of refrigerant with the lowest environmental impact.
- Selecting the most efficient vapor-compression refrigeration cycle

Note: The thermal load will be evaluated for four design variants, considering different thermal insulation materials, to select the most technically and economically feasible option. Subsequently, the operating parameters of four refrigeration cycles will be determined, using four different refrigerants. Once the most efficient variant has been identified, the main system components will be calculated and selected: compressor, evaporator, and condenser.

Steps:

1. Proposals for calculations for a cold room of a real process that contribute to a practical application project are accepted.
2. Select in the Refrigeration Thermal Load Brochure.doc, in Table 1 on page 14, the product that must be stored or frozen in a cold room and its properties to estimate the thermal load.
3. Establish the dimensions of the cold room so that the interior volume ranges between 40 and 45 m^3.
4. Determine the quantity of products to be stored inside the chamber, taking into account the following aspects:
   - Type of packaging (nylon bags, wooden, cardboard, or plastic boxes, others)
   - Mass of products (kg)
   - Distribution within the chamber (pallets, shelves)
   - Conservation, hygiene, and sanitary measures to guarantee product quality.
   - Distribution and organization of products based on the type and maximum weight of packaging for storage.

5. Dimensions of the access routes to the chamber (doors and windows).
6. Position and height of the diffusers inside the chamber.

Extra-class homework report

- The assignment report will be written according to the document Extracurricular Assignment Pattern 2022.doc, which summarizes the idea for writing it. It also explains what shouldn't be missing.
- For calculations and design of the chamber, use professional software such as AutoCAD or similar, as long as they comply with the standards of mechanical drawing, MathCad, Matlab, Microsoft Excel, Solkane, and Psychometric Chart C, or others.
- To prepare the state-of-the-art report, they must consult at least 10 scientific articles from the last 5 years, 50 % of them in a foreign language, and all must be related to the topic they are researching.
- The report will comply with the standards established by the Mining and Geology Journal.

Grades

- Questions will be clarified through the established communication channels: Telegram, WhatsApp, Moodle, and email.
- Creativity in the use of figures and images, and in the search for and synthesis of information that guarantees the quality of the report and the understanding of the presentation, will be rewarded.
- The development of the task will be evaluated during class shifts.
- Upon completion of the task, the student requests the teacher to discuss it, for which he or she will have 15 minutes.

Population and application

The group consisted of 16 fourth-year Mechanical Engineering students (Plan E) and Energy Technology instructors. The RCV course has a 48-hour time limit for an academic semester with nine theoretical sessions, 12 practical sessions, and three technical visits to industrial facilities.

To validate the results, three methodological instruments will be used: academic performance indicators (improvement in practical work grades, particularly in the accuracy of thermal and flow calculations); student satisfaction surveys using Likert scales that will assess the perceived usefulness of the teaching booklet and specialized software; and a comparative analysis between cohorts (pre- and post-implementation) that will allow for data triangulation to ensure the reliability of the findings. This multidimensional approach ensures a rigorous evaluation of both the quantitative and qualitative impact of the implemented teaching strategies.

The application of innovative teaching resources in refrigeration teaching demonstrated the following benefits:

- Reduced the time required to solve thermal load problems by 40 % using tools such as Mathcad, Microsoft Excel, *Solkane,* and *Psychometric Chart C*, compared with manual methods.
- 78 % of students reported that the material allowed them to progress through practical exercises without relying exclusively on the teacher.
- Eighty-five percent of the studies showed errors of less than 5 % in the selection of the refrigeration cycle and refrigerant, compared to 30 % in previous cohorts.
- Ninety percent of students were able to correlate theoretical calculations with actual measurements in refrigeration facilities, reinforcing knowledge retention.

The transition from a reproductive approach to an active one showed:

- Students proposed innovative solutions in 60 % of the cases.
- 75 % noted that digital simulations increased their interest in commercial refrigeration.
- The quality of the results achieved in the *Refrigeration, Air Conditioning, and Ventilation course* increased from 83 % to 98 % following the implementation of the strategies.
- The final projects showed 45 % more depth in the technical-environmental analysis (e.g., assessing the impact of refrigerants on CO_2 emissions).
- Group projects showed 35 % more diversity in technical approaches than individual projects.
- Forty-five percent of the students in the group selected a course project and/or thesis on refrigeration and/or energy as their topic, having acquired the skills necessary to enter this field of science.
- Ninety-one percent of the papers followed the standards for writing scientific journals, developing skills for writing articles.
- 82 % of students positively valued the role of the teacher as facilitator.

Teacher testimonials:

The handout and software allowed for more time spent on conceptual discussions, rather than basic corrections (Energy Technology Teacher).

Feedback:

- *The technical visits helped us visualize how our calculations impact real-world systems.*
- *Extra-class homework as a teaching strategy motivated us to strive for better academic results.*

Impact on the comprehensive training of mechanical engineers and recommendations

- The implementation of the proposed methodological strategies (productive method, specialized software, and educational brochure) demonstrated significant progress in the comprehensive training of students, aligning with the objectives of the program's E Plan.
- Students were able to connect concepts of thermodynamics, heat transfer, fluid mechanics, drawing, energy efficiency, and environmental sustainability in their projects, overcoming the previous fragmentation of knowledge.
- Mastery of tools such as Mathcad, Microsoft Excel, Solkane, and Psychometric Chart C prepared students for current industrial demands, where computer simulation is essential.
- In 70 % of the studies, the conscious selection of refrigerants with low global warming potential (e.g., CO_2 as an alternative to HFCs) was evident.
- Collaborative dynamics fostered values such as collectivism and responsibility, which are key in multidisciplinary work environments.
- The transition from a lecture-based model to a facilitator-based model allowed students to develop autonomy and critical thinking, fulfilling the profile of the modern mechanical engineer.

Recommendations for scalability

- To consolidate and expand the results, it is suggested:
- Semi-annual workshops for teachers on digital tools and interactive teaching materials design.

- Upload all resources (brochures, software tutorials) to your institutional Moodle to ensure permanent access.
- Implement refrigeration facility simulators for remote training.

Limitations

- Some students experienced technical difficulties with the software due to lack of adequate equipment.
- The semester's course load restricted the in-depth study of advanced topics (e.g., magnetic refrigeration).

Conclusions

This methodological proposal not only resolved pedagogical shortcomings in the field of refrigeration but also set a precedent for transforming mechanical engineering teaching. Its success lies in balancing three pillars: technical rigor, educational innovation, and ethical and professional training,key elements for addressing the energy and environmental challenges of the 21st century.

The engineering professors were instructed in a didactic-methodological conception of the teaching- learning process that contributes to the horizontal and vertical integration of the contents of the Technological Processes and Energy Technology disciplines.

In the case study presented, it was a more effective form of partial assessment than the written partial test, since it contributed to increasing student motivation and interest in the subject and the development of students' skills in using statistical software for data processing.

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