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Enhancing the Learning of Key Concepts in Applied Thermodynamics Through Group Concept Maps

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Abstract

This study evaluates the impact of using group concept maps in the teaching of Applied Thermodynamics in the Bachelor's Degree in Industrial Electronics and Automation Engineering. The methodology consisted of selecting topics with a high conceptual load, collaboratively creating concept maps, and subsequently evaluating them by both students and teaching staff. Students achieved average scores above 7/10 in the concept map activity, with teacher and student evaluations averaging 7.8 and 7.3, respectively. Knowledge assessment via pre- and post-tests revealed a 20% increase in concept comprehension. For example, in the topic of Principles of Thermodynamics, the percentage of correct answers on the most complex question increased from 13% in the Pre-Test to 40% in the post-test. In the topic of Refrigeration Cycles, some questions showed an improvement from 18% to 25%. The students' perception of the activity was positive, with an average satisfaction rating of 6.9 out of 10. Furthermore, most students acknowledged that the activity helped them stay engaged with the subject matter and identify errors in their own learning. The high participation in the activity, despite its low impact on the final grade, demonstrates the students' strong motivation for this study approach. Therefore, the implementation of concept maps not only facilitated the understanding of key concepts but also promoted critical reflection and collaborative learning, establishing itself as an effective strategy in the teaching of Applied Thermodynamics.

Keywords: applied thermodynamics teaching/learning; self-study; collaborative work; knowledge assessment; concept maps in engineering education

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1. Introduction

Thermodynamics, a fundamental branch of physics, deals with the study of energy, heat transfer, and work in physical systems. Its application is crucial in various engineering fields, such as mechanical, chemical, electrical, and industrial engineering. The abstract nature of thermodynamic principles, combined with their reliance on advanced mathematics, presents a major challenge in teaching them effectively [1]. Thermodynamics covers a wide spectrum, from energy analysis in microscopic organisms to large industrial equipment, including everyday household appliances. In the industrial field, it addresses problems related to refrigeration systems, steam and gas turbines, electricity generation, and air conditioning systems, among others. In these fields, the engineer plays a crucial role, whether in the design, development, maintenance, or control of processes. This requires competencies that enable them to face specific situations in these contexts. One of the primary challenges in teaching thermodynamics is the difficulty students encounter in visualizing and understanding abstract concepts. Thermodynamics is based on principles that are not easily observable in everyday life, which can lead to a lack of interest and motivation among students [2]. Additionally, applying these principles to complex and multifaceted problems can be overwhelming for many students, especially those lacking a solid foundation in basic concepts [3].

To address these challenges, various pedagogical strategies have been developed to improve the learning and retention of thermodynamic concepts. One of the most effective strategies is the use of open-ended problems, which allow students to explore different approaches and solutions to complex problems. Unlike closed problems, which have a single correct solution, open-ended problems foster critical thinking and creativity, allowing students to develop deeper problem-solving skills [4]. A further method involves the implementation of active teaching methodologies, such as the MEACTER methodology (Active Teaching Methodology for Thermodynamics), which is based on Ausubel's theory of meaningful learning. This methodology promotes active student participation in the learning process through practical and collaborative activities that facilitate the understanding of thermodynamic concepts [5]. Studies that have implemented MEACTER show significant improvement in academic performance and the development of specific competencies in students [6]. On the other hand, the use of technological tools, such as simulations and interactive software, has proven effective in enhancing the understanding of thermodynamic concepts. These tools allow students to visualize and manipulate thermodynamic models, facilitating the learning of abstract principles and their application to real situations. For example, the use of computer simulations allows students to experiment with different scenarios and observe the effects of changes in thermodynamic variables, enriching their understanding and retention of concepts [7,8]. These strategies seek to improve learning in this subject. However, when analyzing the subject itself, this work focuses on engineering education but draws on insights from Physics Education Research (PER), particularly concerning the teaching and learning of thermodynamics. Comprehensive reviews of thermodynamics training across different disciplines identify persistent conceptual difficulties and the need for pedagogical strategies that promote deeper understanding. The importance of helping students connect abstract principles with practical applications is highlighted, an approach aligned with the use of concept maps in this work. By encouraging students to visualize the relationships between concepts such as energy, heat, and entropy, the activity seeks to address some of the challenges identified in the PER literature [9,10].

Concept maps are a widely used strategy in higher education [11,12], which have proven to be a valuable pedagogical tool in higher education. Concept maps are graphical tools that allow the organization and representation of knowledge visually, facilitating understanding and meaningful learning. These maps enable students to organize and visually structure information, identifying relationships and hierarchies among different thermodynamic principles.

Different theories justify the effectiveness of concept maps in learning:

- Ausubel's Subsumption Theory: Concept maps facilitate meaningful learning by organizing knowledge hierarchically and connecting it with prior knowledge [13].
- Paivio's Dual Coding Theory: Concept maps use both verbal and visual elements, enhancing retention and understanding of information by employing two distinct but interconnected coding systems [14].
- Sweller's Cognitive Load Theory: Concept maps reduce extraneous cognitive load by visually simplifying information and organizing it logically, helping students manage complex material without overloading their working memory [15].

These theories highlight how concept maps can improve learning by organizing knowledge meaningfully, using multiple coding modalities, and reducing cognitive load.

Therefore, constructing concept maps fosters meaningful learning, as students must select and connect key concepts, facilitating a deeper and more lasting understanding. Their use in higher education has increased significantly due to their ability to help students structure and relate complex concepts [14]. Conceptual maps offer several benefits across different contexts. They allow for the clear and hierarchical organization of ideas, making complex topics easier to understand [16]. By requiring students to analyze and synthesize information, they promote active and meaningful learning. The visual representation of information aids in long-term memory retention, as the human brain processes visual information more efficiently. Additionally, conceptual maps are adaptable to various contexts, from teaching complex subjects to project planning [17]. They stimulate critical thinking by encouraging students to reflect on information and identify relevant relationships between concepts. Furthermore, they facilitate the communication of complex ideas clearly and quickly, which is particularly useful in time-constrained situations.

The implementation of concept maps in higher education has required significant efforts from institutions and educators, including training teachers in their use and how to integrate them into the curriculum. Additionally, educational institutions have developed and provided resources, such as guides and templates, to help students and teachers create concept maps effectively. Research has also been conducted to evaluate the effectiveness of concept maps in improving learning, demonstrating that they can significantly enhance understanding and retention of information.

Therefore, it can be confirmed that concept maps are powerful tools that facilitate the organization and comprehension of complex information in higher education. Through their implementation, students can develop more active and meaningful learning, improve their memorization and critical thinking skills, and communicate complex ideas more effectively. The efforts made to train teachers, develop resources, and evaluate the effectiveness of concept maps have demonstrated their value in various disciplines and educational contexts [16]. With their ability to adapt to different needs and promote deep learning, concept maps continue to be an invaluable tool in higher education.

Conceptual maps have been used in various disciplines and contexts within higher education, as shown in Table 1:

Table 1. Application of conceptual maps in different disciplines [18–22].

Discipline	Description	Use
Health Sciences	Conceptual maps are used to teach and assess knowledge about physiological and pathological processes in physiotherapy or nursing programs.	These maps help students visualize the interactions between different systems of the human body.
Social Sciences	Conceptual maps are used to represent complex theories and models in disciplines such as sociology and psychology.	These maps help students understand the relationships between different concepts and develop a deeper understanding of the theories studied.
Education	Conceptual maps are used in teacher training programs to teach pedagogical strategies and learning theories.	These maps allow future teachers to visualize how different educational approaches interrelate and how they can apply them in the classroom.
Business Administration	Conceptual maps are used in business administration programs to teach and analyze business strategies, business models, and organizational processes.	These maps help students understand how different elements of an organization interact and affect overall performance.
Engineering	Conceptual maps are used to explain and relate technical concepts such as physical principles and production processes.	These maps facilitate the understanding of how different components and processes interact in a system.

The construction of a concept map consists of four fundamentals, starting with identifying the concepts to be incorporated into the map, followed by selecting the most general concept to arrange the rest of the concepts and connecting them with lines representing the relationships between them, with a final review necessary to consolidate the ideas. Therefore, the complete execution of each of these stages is essential to ensure its effectiveness as a learning tool.

For all these reasons, this work presents the results of the development of conceptual maps by students of Applied Thermodynamics in the Degree in Industrial Electronics and Automation Engineering, as an evaluable tool for the comprehension of complex concepts.

In this study, concept maps were used as a central tool to promote meaningful learning in thermodynamics. Students were instructed to create individual maps that reflected the key concepts of the unit, organized hierarchically from general to specific. Each map had to include linking phrases to define the relationships between concepts, ensuring semantic clarity and logical coherence. The activity was designed not only to reinforce content understanding but also to foster analytical thinking and peer interaction. Evaluation criteria, shared in advance, included conceptual clarity, structural organization, creativity in visual representation, and alignment with the theoretical content covered in class.

2. Materials and Methods

This activity has been implemented for the first time in the Applied Thermodynamics course of the Bachelor's Degree in Industrial Electronics and Automation Engineering at the Universidad Rey Juan Carlos (URJC). This is a mandatory 4.5-credit course that is part of the Thermal Engineering branch, along with the "Heat Transfer" course. The learning outcomes recorded in the Register of Universities, Centers, and Degrees (RUCT) [23] are as follows:

- Understand and apply thermodynamic relationships and diagrams to calculate the properties of substances.
- Understand the principles of Thermodynamics and know how to apply them in performing energy and/or entropy balances of interest in engineering.
- Understand thermodynamic cycles of power and refrigeration, as well as their main applications in engineering.
- Be able to perform energy efficiency analyses in power and refrigeration cycles.
- Understand and comprehend the fundamentals of psychrometry and its application to different devices and processes.
- Reasonably solve basic thermodynamics problems.

To achieve these outcomes, the course content is divided into 5 blocks with different teaching loads, summarized in Table 2:

Table 2. Programming developed in the course.

Topic	Description
1: Introduction	Basic concepts of thermodynamics.
2: Principles of Thermodynamics	Zeroth Law. First Law in closed and open systems. Second Law in closed and open systems.
3: Thermodynamic properties of pure substances	P-V-T behavior of pure substances. Equations of state. Property tables. Thermodynamic properties of gases and liquids
4: Applied thermodynamics to thermal machines	Introduction to thermal machines. Carnot cycle. Cycles of reciprocating engines (Otto and Diesel). Cycles of rotary engines (Rankine and Brayton). Modifications of rotary engine cycles. Refrigeration cycles.
5: Psychrometry	Humidity. Enthalpy of moist air. Mixtures of moist air. Psychrometric chart.

Regarding teaching methodologies, the course is delivered through lectures, which consist of the professor presenting the syllabus with the help of various audiovisual aids, supporting the expository methodology with dynamization techniques. These lectures are complemented by activities such as problem-solving sessions and practical case studies, whose effectiveness is directly proportional to the level of engagement in the theoretical sessions. Therefore, by having students create concept maps, the aim is for them to conduct a preliminary study of theoretical concepts before tackling problem-solving. Consequently, the course evaluation system consists of two re-assessable exams accounting for 70% of the final grade, two group seminars for problem-solving with and without the use of software, accounting for 30% of the final grade, and a 5% bonus for the creation of group concept maps.

The group of 63 students who took Applied Thermodynamics in the 2023–2024 academic year has an average age of 21.5 years, with a marked gender disparity (87% men and 13% women). In terms of academic performance, a total of 70% of the students were enrolled in the course for the first time, indicating that the majority were encountering the subject for the first time. Meanwhile, 27% had previously taken the course but had not passed the final exam, and 3% had enrolled in the course in at least two previous academic years. To ensure the comparability of the results with the previous academic year (2022–2023), additional information about the student cohort has been considered. Specifically, the admission cut-off grade for the degree program was 9.95 in the year without the use of conceptual maps, and 9.70 in the year in which this methodology was implemented. These values indicate that there were no significant differences in the academic level of the students between the two cohorts, supporting the validity of the comparative analysis.

The methodology begins with the selection by the teaching staff of topics with a high load of key concepts, which will be susceptible to applying this activity of elaborating conceptual maps (CM) for self-study. Once the lectures on the selected topics are finished, work groups have been generated to elaborate the CM. For the collaborative phase of the activity, students were organized into small groups of 3 to 5 members. Group formation was based on voluntary self-selection within each class section, allowing students to work with peers they felt comfortable collaborating with. This approach aimed to foster a positive working environment and encourage active participation. In cases where students did not choose a group, the teaching staff assigned them to existing teams to ensure full inclusion. It is a collaborative activity, promoting teamwork and effective communication. The grading of the CM is carried out both self- and co-evaluatively by the students and the teacher [24], accounting for 5% of the total grade of the subject.

During the in-person session, the teaching team initially presented a visual guide (Figure 1) to reinforce expectations regarding the development and assessment of concept maps. The figure presents the key components of a concept map along with a generic example and highlights the four key criteria used during assessment: conceptual clarity, hierarchical organization, creativity in visual representation, and alignment with theoretical content. These criteria are expected to serve as reference points for creating maps. Following this introduction, the grouped students developed concept maps outside of class, which were uploaded to the virtual classroom. Later, in another in-person session, students had access to all groups' concept maps for assessment. Although no formal rubric was used, the evaluation process was consistently informed by the four criteria introduced earlier and illustrated in Figure 1, which served as shared reference points for both students and instructors throughout the assessment process. Students were asked to analyze and revise each map to understand the different approaches to content and structure used by their peers. The evaluation activity was conducted using a dynamic digital tool (Wooclap. available in the learning management system of URJC) to promote participation and ensure objectivity [25]. Each student assigned a score from 0 to 10 to the maps, based on the predefined criteria. The final grade for each concept map was determined by combining two components: 50% from peer evaluation and 50% from the teaching staff's assessment, which followed a more detailed and expert-based framework.

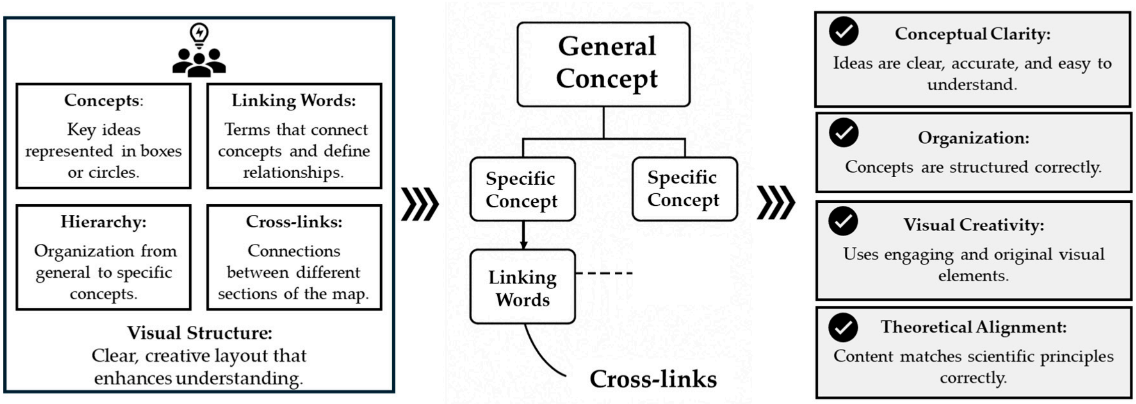


Figure 1. Concept map components and evaluation criteria, as explained during class.

Simultaneously, intending to measure improvements in the understanding of the concepts addressed, the teaching staff prepared a questionnaire using once Wooclap tool, which is commonly employed at Universidad Rey Juan Carlos to gamify classroom activities. The questionnaire was completed by students at two different times: before and after the conceptual map was elaborated [26]. The tests consisted of a set of multiple-choice questions designed to assess conceptual and applied understanding of the topics. Some questions required students to perform calculations or compare properties, both intensive and extensive, while others focused on theoretical aspects, such as defining key concepts or identifying concepts.

To assess students' perceptions of the concept mapping activity and its impact on their learning process, an ad hoc questionnaire was designed and administered online before the final exam in the ordinary call. The instrument included two types of items: a numerical rating scale from 0 to 10 to evaluate overall satisfaction with the activity, and a 10-point Likert-type scale to measure agreement with specific statements regarding its usefulness for learning. These statements explored whether students considered the creation and evaluation of concept maps helpful for improving their understanding of the topics, reinforcing unclear concepts, and preparing for assessments. Additional items addressed the perceived usefulness of peer presentations and the overall enjoyment of the activity. The questionnaire was distributed through the institutional learning platform, ensuring accessibility and anonymity. This approach allowed us to distinguish between perceived learning benefits and affective engagement, and to gather honest and reflective feedback from students about their experience with the methodology.

3. Results and Discussion

Herein, the results and a brief discussion of the implementation of the explained methodology are presented for the subject of Applied Thermodynamics in the Degree in Industrial Electronics and Automation Engineering for the academic year 2023–2024.

3.1. Selection of Topics by the Teaching Staff

As mentioned in the Method section, the course content is structured into five topics, some more theoretical and others more practical. The purpose of this activity is for students to prepare those topics that are heavily loaded with new fundamental concepts before tackling problem-solving and practical cases. There are several topics in the course for which the creation of these maps is feasible, but two of them have been selected based on the following criteria:

- Course Progression: In the early topics, student engagement is low, and in the final topics, there are usually final exams for other subjects, so the time available for creating the maps is limited.
- Difficulty of the Concepts in Each Topic: Some topics have a heavier load of new concepts than others, where the creation of the maps can be more useful.
- Conducting Assessable Activities of the Course During the Semester: Two seminars are planned, and the creation of the conceptual map should help in their preparation.

Therefore, the selected topics were:

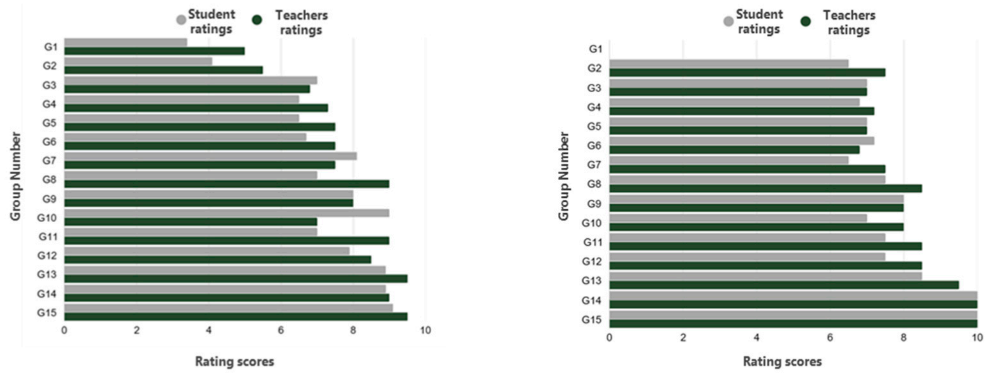
1. Principles of Thermodynamics: This includes new concepts that students must assimilate before solving problems and advancing in the application of thermodynamics to thermal machines.
2. Thermodynamic Refrigeration Cycles: This includes concepts already covered, but the application is in refrigeration cycles instead of thermal machines.

3.2. Creation of the Maps by the Students

Once the teacher explains the theoretical part of each selected topic, the students collaboratively and group-wise create the corresponding conceptual maps (CMs). This activity, designed to foster meaningful learning and the integration of concepts worked on in class, allows students to structure and hierarchize information visually, thus facilitating a deep understanding of the content. The CMs are anonymously uploaded to the Virtual Classroom through a task specifically enabled for this purpose. This delivery method, designed by the teachers within the platform, promotes fairness and impartiality in evaluation, while providing a safe space for students to share their productions in a non-judgmental environment, prioritizing the focus on the quality of the work presented. In this way, a balance is achieved between theoretical teaching and practical application, aligning the activity with the established educational objectives.

3.3. Evaluation of the Maps by the Students

As described in the Materials and Methods section, students participated in a peer evaluation activity in which they assessed the conceptual maps created by their classmates using a numerical scale from 0 to 10, based on predefined criteria. The final grade for each map was composed of 50% of student evaluations and 50% from the teaching staff. Regarding the results obtained, the students developed conceptual maps that, in general, presented a high level of completeness and conceptual rigor, which resulted in average grades higher than 7 out of 10 in this activity. The ratings of the concept maps from the first submission, which was something new for the students, had an average value of 7.1 ± 1.6 for the students, reaching a higher value with less deviation for the teaching staff (7.7 ± 1.3). Subsequently, in the second submission, the average ratings were higher, but their deviation also increased in both cases, being 7.3 ± 2.0 and 7.8 ± 2.1 for students and teachers, respectively. Figure 2 shows in detail the grades given by both the teaching staff and the students, along with the arithmetic mean resulting from both evaluations.



(**a**) (**b**)

Figure 2. Ratings from 0 to 10 assigned by students (grey bars) and teaching staff (black bars) to each group's concept map (G1 to G15) for the topics of (**a**) Principles of Thermodynamics and (**b**) Refrigeration Cycles.

This graphical representation allows for a comparative visualization of the evaluations of each group, highlighting the consistency between both perspectives and evidencing the overall quality of the work carried out by the students. Specifically, it is noteworthy how the grades given by the teaching staff and the students are quite similar, especially in the highest grades, which could indicate that the students clearly understand the items or indicators that are valued in the creation of a conceptual map. It can be observed that the groups that received low grades (below 5.0) for their first conceptual map improved in the creation of the second one, achieving a better score in this submission, showing positive learning. Beyond these general trends, certain cases stand out and merit further discussion. For example, in panel (a), the notably higher marks given by students to group G10 may reflect factors such as group dynamics or perceived effort, rather than strict adherence to the evaluation criteria. In panel (b), both staff and students awarded full marks to groups G14 and G15. These conceptual maps were distinguished by their clarity, originality, and visual impact, which set them apart from the rest.

The differences observed between the scores assigned by students and those given by the teaching staff may be attributed to several factors. Students often adopt a more lenient or empathetic approach, possibly influenced by social dynamics or limited experience in applying academic evaluation criteria. In contrast, the teaching staff followed a structured and analytical framework based on pedagogical standards, which may explain the slightly higher average scores and lower variability. Furthermore, while students may have focused more on visual creativity and general understanding, professors placed greater emphasis on conceptual accuracy, hierarchical organization, and alignment with course content. These differences have been the subject of previous studies [27], demonstrating that peer assessments tend to align better with teacher evaluations when global criteria are well understood, but diverge when multiple specific dimensions are assessed. Therefore, this activity is in line with related work [28], in which a meta-analysis found that peer assessment generally improves academic performance and correlates with teacher ratings, although its effectiveness depends on contextual and instructional factors. These findings support the idea that peer and expert evaluations offer complementary perspectives in formative assessment and contribute to a more holistic understanding of student learning.

Analysis of the concept maps revealed several recurring errors that provided valuable insight into student understanding and areas for improvement. The most common problems included a lack of conceptual clarity, with vague or ill-defined ideas; poor hierarchical organization, where concepts were not structured from general to specific; and a lack of coherence with the theoretical content, suggesting superficial engagement or misunderstandings. Furthermore, some maps exhibited redundancy through repeated concepts, disconnected nodes that fragmented the overall structure, and excessive use of decorative elements that made reading difficult. Incorrect or missing relationships, such as misused arrows or linking phrases, were also frequently observed. These findings were instrumental in guiding feedback and refining teaching strategies to achieve more coherent and meaningful learning outcomes.

On the other hand, the high participation in the activity is noteworthy, as previously explained, the impact on the final grade of the subject is very low, and of the 16 groups, almost all completed both maps.

3.4. Learning Assessment Through Pre- and Post-Tests

Before starting the creation of the conceptual map, students answer a series of questions related to the syllabus taught, designed to assess their initial level of knowledge on the content covered in class (Pre-Test). This instrument provides a preliminary view of the students' understanding of the subject before carrying out the collaborative activity. Subsequently, once the groups complete the evaluation of the other conceptual maps, the same questionnaires (Post-Test) are applied again to measure the progress in knowledge acquired after completing this activity. Table 3 presents the results of these questionnaires, showing the percentages of correct answers for each question both before and after creating the conceptual maps.

Table 3. Percentage of correct answers in the pre- and post-concept map knowledge test on the selected topics.

Principles of Thermodynamics			**Refrigeration Cycles**		
	Pre-Test	**Post-Test**		**Pre-Test**	**Post-Test**
Q1	56%	74%	Q6	71%	92%
Q2	95%	95%	Q7	18%	25%
Q3	22%	43%	Q8	39%	45%
Q4	20%	40%	Q9	33%	48%
Q5	13%	40%	Q10	68%	80%

An increase can be observed in the percentage of students who correctly answered the questions posed after creating the conceptual map. This suggests that students engaged actively, resulting in more meaningful learning during its creation, evidencing the success of the activity in consolidating key concepts of the subject. However, there are 3 questions in each topic that less than half of the class managed to answer correctly. Therefore, this activity has also served to identify areas where students have significantly improved, as well as those that may require greater pedagogical reinforcement, providing a useful tool to evaluate the effectiveness of the activity in the learning process.

Analysis of the responses revealed that questions involving applied reasoning, such as calculations or comparisons, were generally answered more frequently and correctly by students. In contrast, the questions that remained unanswered by the majority were predominantly conceptual and theoretical. These items required a deeper understanding of abstract principles and systemic thinking, which may take longer to assimilate. This suggests that while concept mapping supports meaningful learning, certain theoretical concepts may require additional instructional support or time for reflection to be fully understood.

The interpretation of learning gains in this study must consider the potential influence of repeating identical questions in the pre- and post-tests. While concept mapping (CM) is designed to promote meaningful learning through the organization and integration of knowledge, the use of identical test items may introduce a test–retest effect, where improvements in post-test scores are partially due to item familiarity rather than genuine conceptual development. Literature can be found emphasizing that pre-/post protocols using the same instrument are effective in measuring learning gains, especially when concept inventories are used to assess conceptual understanding [29,30]. Nevertheless, this approach may also inflate results if not carefully controlled.

3.5. Student Perception Assessment

Finally, students were surveyed about the methodology used to evaluate their perception of the creation and evaluation of the conceptual maps. They were asked to rate the conceptual map activity from 0 to 10. The students' satisfaction survey reflected a positive assessment of the group activity, achieving an average score of 6.9, the distribution of which is shown in Figure 3.

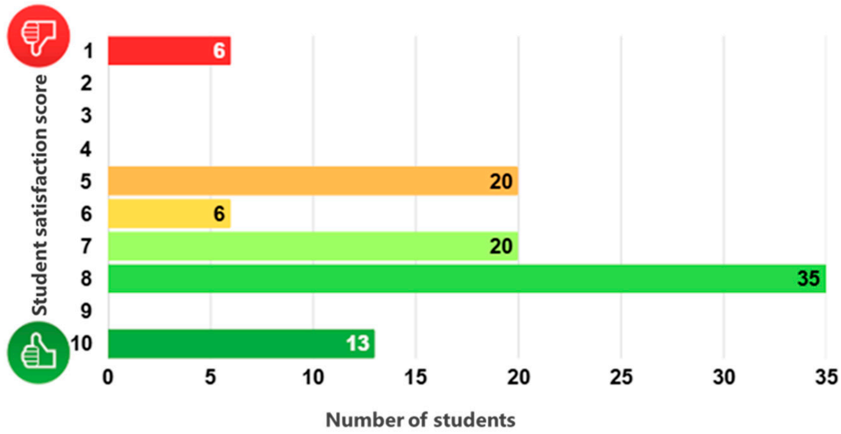
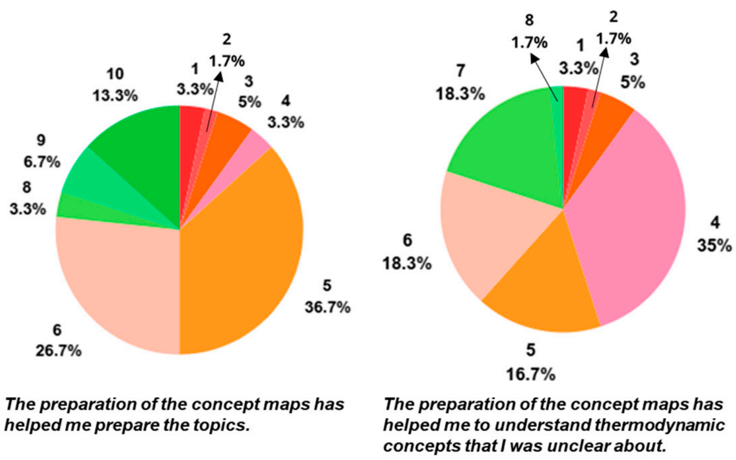


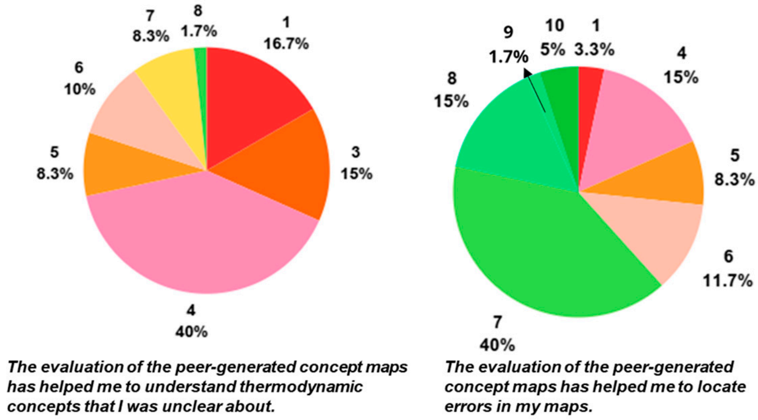
Figure 3. Distribution of student satisfaction scores (0–10) regarding the new methodology.

In order to make a deeper assessment, a Likert scale was used to determine whether the students consider the preparation and evaluation of the concept maps to be useful for improving their learning, being 1: totally in disagreement with the statement (red) and 10: totally in agreement (green). The color gradient reflects the progression from disagreement to agreement, with intermediate tones (orange, pink, yellow, light green). Figure 4 shows that students did not strongly perceive the creation of concept maps as directly helpful for preparing the topics or clarifying concepts.



(**a**)

Figure 4. *Cont.*



(**b**)

Figure 4. Evaluation of the methodology using the Likert scale from 1 (strongly disagree, red) to 10 (strongly agree, green) for (**a**) "*The preparation of the concept maps has helped me to prepare the topics and to understand thermodynamic concepts that I was unclear about*" (**b**) "*The evaluation of the peer-generated concept maps has helped me to understand thermodynamic concepts that I was unclear about and to locate errors in my maps*".

However, they did find peer presentations useful for identifying errors in their own maps. In this activity, the goal was not only to promote learning through the creation of concept maps, but also to encourage reflection and self-assessment through peer evaluation. Interestingly, while students did not consider peer evaluation particularly effective for reinforcing concepts, they did value it as a tool for recognizing their own mistakes. Despite the limited perception of direct learning benefits, the activity was widely enjoyed, suggesting that students appreciated its collaborative and participatory nature.

3.6. Achieved Grades

Once the complete activity has been developed, including the creation and evaluation of the maps, the results obtained (with CM) in each of the assessable activities have been compared with those obtained in the same activities in a previous academic year, in which this teaching methodology was not used (without CM). Table 4 shows the results, and it can be observed in all cases that the students' grades are higher on this course than in previous ones in the four evaluated activities (two seminars and two tests). To evaluate the effect size caused by this methodological change, Cohen's d has been calculated, based on the differences in the mean grades and the weighted standard deviation [31]. If it presents a value lower than 0.20, it indicates no effect; if it reaches values between 0.21 and 0.49, it refers to a small effect; likewise, for values between 0.50 and 0.70, it indicates a moderate effect, and finally, values higher than 0.80 indicate a significant effect (bond).

It is noteworthy that in both seminars and in Test 1, the differences between the two courses are considered to have a moderate effect (Cohen's d value is greater than 0.50); however, in Seminar 2, the differences can be considered significant. This result may be because in the development of Conceptual Map 2, the concepts worked on are closely related to the problems that students must solve in Seminar 2, and the prior work dedicated by the students translates into a more satisfactory resolution of these problems.

Table 4. Grades obtained in the evaluable activities of the previous 2022–2023 academic year (without MC) and the 2023–2024 academic year (with MC).

		2022–2023	**2023–2024**
Seminar 1	Main	6.5 ± 3.0	7.5 ± 0.9
	d-Cohen	0.53	
Seminar 2	Main	4.9 ± 2.9	6.5 ± 3
	d-Cohen	0.55	
Test 1	Main	3.1 ± 2.8	4.7 ± 2.0
	d-Cohen	0.66	
Test 2	Main	2.8 ± 1.9	4.4 ± 1.9
	d-Cohen	0.82	

To complement the interpretation of these effect sizes, 95% confidence intervals (CI) were calculated for each Cohen's d value, providing a range within which the true effect size is likely to fall and offering a more nuanced understanding of the impact of the methodological change. For Seminar 1, d = 0.53 (CI: 0.015–1.045); for Seminar 2, d = 0.55 (CI: 0.034–1.066); for Test 1, d = 0.66 (CI: 0.140–1.180); and for Test 2, d = 0.82 (CI: 0.293–1.347). Although the intervals vary in width, all points toward positive effects of the intervention, reinforcing the conclusion that the use of concept maps contributed to improved academic performance. Therefore, it can be concluded that the use of this methodology ensures that students prepare the material before tackling the problems, leading to better learning, which translates into better academic results.

3.7. Methodological Constraints and Opportunities for Improvement

This study presents the first implementation of a methodology based on concept mapping and peer evaluation in a higher education context. While the results are promising, several limitations must be acknowledged. First, the absence of a control group prevents direct comparison with other instructional strategies, such as traditional lectures or retrieval-based learning. Second, the findings are based on a single cohort, which limits the generalizability and statistical robustness of the conclusions. Future studies should consider longitudinal designs across multiple academic years to assess the consistency and evolution of learning outcomes. In future implementations, it would be beneficial to incorporate control groups, delayed post-tests, and mixed method approaches to better isolate the effects of the methodology. Expanding the scope to include multiple cohorts and disciplines would also enhance the validity and applicability of the findings.

4. Conclusions

The teaching of Applied Thermodynamics in engineering presents significant challenges due to the abstract nature and conceptual density of its content. This study explored the implementation of collaborative concept mapping combined with peer evaluation as an active learning strategy in the subject, yielding promising results across multiple dimensions.

The creation and evaluation of conceptual maps facilitated the structuring and integration of key concepts, promoted collaborative learning, and encouraged student engagement. The peer and teacher evaluations of the maps showed consistent results, with average scores above 7 out of 10, and a clear improvement in the second submission. This suggests that students understood the evaluation criteria and benefited from the iterative nature of the activity. Learning gains were also observed through pre- and post-tests, with a 20% average increase in correct responses. However, some conceptual questions remained challenging, indicating the need for complementary instructional strategies to reinforce abstract content. The activity was particularly effective in improving performance on applied reasoning tasks. Student perception of the methodology was moderately positive, with an average satisfaction score of 6.9 out of 10. While students did not strongly associate the creation of maps with improved conceptual understanding, they valued peer evaluation as a tool for identifying errors and reflecting on their own learning. A comparative analysis of academic performance between cohorts revealed higher grades in all evaluated activities when concept mapping was used, with moderate to significant effect sizes (Cohen's d ranging from 0.53 to 0.82). These results suggest that the methodology helped students prepare more effectively for problem-solving tasks. Despite these encouraging outcomes, the study has limitations. It was conducted with a single cohort and lacked a control group, which restricts the generalizability of the findings. Future implementations should consider longitudinal designs, delayed post-tests, and mixed method approaches to better isolate the effects of the intervention.

In conclusion, collaborative concept mapping combined with peer evaluation appears to be a valuable strategy for enhancing learning in Applied Thermodynamics. Its integration into other engineering subjects could help validate its broader applicability and contribute to the development of active learning methodologies in STEM education.

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