Teaching Thermofluids Sciences from an Interdisciplinary Perspective

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***Abstract*—Thermal and fluid sciences, as taught in Mechanical Engineering undergraduate programs, have traditionally followed an intrinsic separation. Typically, thermodynamics, heat transfer, and fluid mechanics are delivered as separate courses. The leap from the fundamental thermofluids subjects to the application courses, in which the aforementioned subjects must be involved to obtain optimal thermal systems, demands significant effort from the students to combine all of them together. In this framework, this work presents an innovative approach that combines these subjects following a different learning path, adopting a Challenge-Based Learning (CBL) approach by solving a real and relevant challenge in partnership with both industry and NGO partners. The results, observations, and conclusions of implementing this novel approach for teaching thermal sciences are presented.**

***Keywords*—educational innovation, energy, higher education, interdisciplinary, mechanical engineering, professional education, thermal sciences**

I. INTRODUCTION

Thermodynamics, Heat Transfer, and Fluid Mechanics (T-HT-FM) are traditional subjects in Mechanical Engineering programs. Worldwide, engineering programs deliver these subjects at the junior/senior level during the coursework, while an applied course that relates the three of them in an energy application is frequently taken at the end of the formation. Most energy applications require previous knowledge from T-HT-FM, e.g., turbomachinery. For this reason, energy applications in many courses and textbooks are also included as part of the syllabus or content of the three main subjects T-HT-FM. When students encounter applications related to energy and thermal sciences, all the previous disciplines need to be interdisciplinary combined to successfully design, calculate, and manufacture a functional energy system. As a result, educational institutions face the challenge of providing a smooth transition from the fundamental thermal sciences courses (T-HT-FM) to the applications. From the pedagogical perspective, different possibilities can be explored to innovate this traditional learning path. For example, a course might combine all the energy disciplines from the beginning. This would exhibit advantages and disadvantages that should be analyzed in detail.

In this framework, this work presents and discusses a novel curriculum that combines T-HT-FM in different Training Units (TUs). Previous works that implemented similar course combinations have been reported by different authors [1–9], mainly focusing on combining the disciplines towards a project or specific goal, but not involving all three main subjects T-HT-FM in some cases. In other works, different learning techniques to study energy, thermal, and engineering sciences have been proven to impact the learning process [10–25]. The approach explored here combines Problem-Based Learning (PBL) and CBL with a new curriculum, which includes mixed topics in different TUs of the three main disciplines. T-HT-FM are still studied as separate subjects in parallel with TUs containing mixed topics of the disciplines. By analyzing performance evaluation scores and perception surveys, this work describes the results of combining thermofluids disciplines towards the design of energy systems and the development of engineering competencies, compared to an approach of teaching the disciplines separately.

This work is organized as follows. Section II describes relevant context and terminology. Moreover, this section presents the detailed curricula of the mechanical engineering student, where the method was applied, the syllabus of each TU, and how CBL is applied through the solution of a challenge. Section III presents the numerical evaluation of the students in the TUs and the perception of the students towards these TUs, evaluated through a survey applied at the end of the TU. Finally, some concluding remarks about this approach are given in Section IV.

II. METHOD

Mechanical Engineers apply thermal sciences to solve problems related to energy conversion. Energy conversion is a complex discipline that in late years has become of huge importance to society due to limited fossil fuel resources and the carbon footprint of this process. To solve current challenges related to energy, it

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is not enough to have fundamental engineering knowledge, but competencies related to the ability to face these challenges are also required. For this reason, different educational institutions have proposed new curricula for their programs with different approaches with the main goal to develop engineering competencies. One example is the "Tecnologico de Monterrey", a higher education institution that has proposed a novel approach in their curricula programs named "Tec21", implemented in August 2019 [26, 27]. This initiative focuses on the development of competencies through novel TUs, instead of traditional courses [10, 28]. Two different types of TUs are delivered. The first type is similar to a traditional course in the contents, but PBL is used to develop related competencies. These TUs are named subjects within the programs. The most innovative part of the program is the second type of TU called "block". In the block, an interdisciplinary approach and CBL are adopted. Here a training partner from industry [12] or society is included, and the students must work towards the solution of a challenge proposed by the training partner and the block professors. In this novel curriculum, proposed by "Tecnologico de Monterrey", for Mechanical Engineering, the thermal sciences were redesigned in different TUs to achieve the goal of developing competencies related to energy conversion with the characteristics described before. In this new program, the TUs related to energy are studied during the junior year, i.e., the fifth and sixth semesters. The TUs studied as subjects are:

- Fluid Mechanics Fundamentals (FMF).
- Analysis of the Energy Conversion Processes (AECP).
- Heat Transfer Modeling (HTM).

AECP is equivalent in content to an Introduction to Thermodynamics course. For the other two courses, equivalent topics such as an Introduction to Fluid Mechanics and Heat transfer are included. The block TUs are:

- Design of Thermofluidics Systems (DTS).
- Design of Thermal Machines (DTM).

The block TUs are interdisciplinary for thermofluidic disciplines. In detail, each TU contains interdisciplinary modules that enhance the development of engineering competencies, allowing the student to face and successfully solve the challenge proposed by the training partner. The modules for DTS are:

1) Viscous flow in pipelines and pump selection.
2) Aerodynamics.
3) Differential formulation of momentum and energy equations.
4) Computational Fluid Dynamics (CFD).
5) Ethics with a human sense.

The modules for DTM are:

1) Properties of thermodynamic substances.
2) Thermodynamic cycles.
3) Turbomachinery.
4) Heat exchangers.
5) Combustion.
6) Alternating Current Circuits (AC).

Let us describe the DTS block to explain the combination of theoretical and practical contents. The TU is taken for 5 weeks, involving a total of 80 hours. During the first 4 weeks, 12 hours are taken by the modules to teach the theoretical and practical content related to the modules. The learning method for the modules is the choice of the lecturer. Traditional lectures flipped learning, gamification, or problem-based learning can be used. Evaluation instruments such as homework, quiz, essays, or small projects are allowed. The instructor also applies lab practices regarding the contents of the module, which are related to the proposed challenge. Only 4 hours per week are dedicated to solving the challenge during the first 4 weeks. During this time the students start getting involved in the challenge through visits to the training partner, requirements surveys, and state-of-the-art investigation of existing related technology. After the second week, it is expected that the first proposal is discussed with the students. To enhance collaborative learning, the challenge is solved by groups of students. Each group has five or six students. Finally, the fifth week is completely dedicated to the solution to the challenge, it is a full immersive week without lectures or activities related to modules. At the end of the TU, the groups present their solutions to the group of professors and the training partner for feedback and evaluation.

In this work, we report the experience of the implementation of the DTS block during the fall term of 2022, with a group of 27 students and three different lecturers. The challenge proposed by a local pump manufacturer, a local NGO, and a group of professors, was the design and construction of a human-powered pump. The NGO is involved with rainwater collection and distribution of clean and accessible water to the vulnerable population. The challenge offered many opportunities to the students. The design of the mechanism was developed by a previous TU related to mechanical design, allowing the students to connect different disciplines of their major. The final product of the TU is related to different Sustainable Development Goals (SDGs). The connection of the final product with a direct impact on the SDGs and the technical part allowed the development of disciplinary and transversal competencies. Also, the project's technical part involves thermofluids disciplines that are typically studied as separate subjects, as explained above. In this case, those topics were taught as support knowledge to develop competencies through the solution of a real and relevant challenge.

The following section will present a discussion about the learning effectiveness and motivation of the students taking the DTS block, delivered as described, in comparison with students taking two other subjects related to energy: AECP and HTM. It is important to mention that the approaches were implemented in the same group of students in three different TUs. The results presented are the collection of data from the professor-lecturer of the AECP and HTM TUs. The same professor was part of the team of professors involved in the TU block DTS, and only the collection of data for the modules and activities in which the same professor was involved are included. Data related to TUs in which this professor was not involved, such as FMM, or TUs that were not implemented during the same semester are not included in the analysis to avoid biased results.

III. RESULTS

The final product of the challenge proposed by the training partners was a working prototype of a human-powered pump. Fig. 1 shows one of the prototypes while it is being tested. Evidence such as a final presentation of the working prototype, operating manuals, and improvement proposals were delivered by all the teams.

A comparison of academic performance is presented. The academic performance is graded between 0–100. Fig. 2 compares the final scores of three different modules taken in different TUs. The first two modules are from the subject approach AECP and HTM. The third module belongs to the block approach. The modules have different content, however, all of them deal with theoretical content related to T-HT-FM. The contents of the modules might represent different levels of difficulty for different students. It is relative how difficult are the contents of the different modules for each student. However, all the contents studied in the modules are typical knowledge of thermal sciences being related within them, and similar instruments such as homework, activities, and quizzes were used to obtain the module grade. As the content studied in the modules is related and similar instruments were used to obtain the module grade, comparing the student's performance during the modules provides insight into the pedagogical method presented here. For the TU AECP the median score is 100, however in this case, 3 outliers with a score of 40 were observed, the lower limit was 60 and the 25th percentile was 80. HTM presents a median of 92.5, and no outliers were observed. The lower and upper limits observed were 85 and 100 respectively. The 25th and 75th percentiles were 90.63 and 98.75. The DTS block shows a median of 97, a lower and upper limit of 75 and 100 respectively, and the 25th percentile as 89.7.

Fig. 1. Final working prototype built by one of the teams.

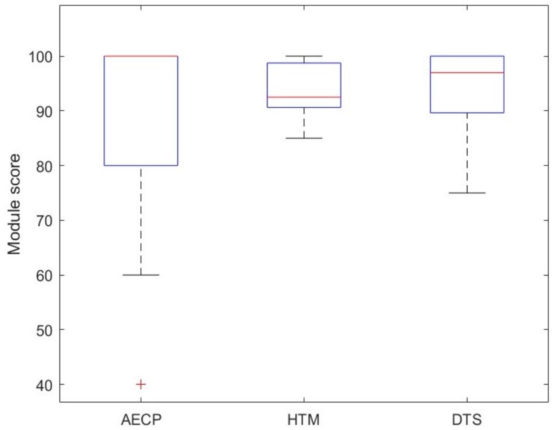

Fig. 2. Modules score statistics.

The results in the evaluation of theoretical content taught in the modules with different TUs show no difference in the performance of the students. These results imply that using an interdisciplinary approach in the DTS TU has no effect on the understanding of theoretical concepts, despite the fact of using an interdisciplinary approach related to thermal sciences. The final scores of the TUs are shown in Fig. 3. The following information is observed: the median of the final grades for AECP, HTM, and DTS are 98.5, 95.4, and 93.8 respectively. In the same order, the lower limits are 92.4, 89.15, and 86.3. It is also observed that the final grades are more spread for the DTS TU, meaning that students did not show a uniform performance as observed for the two other TUs. From the previous results, we can suggest that when the theoretical content is taught in separate modules, no effect on the modality of the TU is observed in the score of the modules. However, when the TU is graded with all the modules and activities of the TU, a lower score is observed with the block modality. It can be implied that the block approach is more challenging to the students due to the nature of combining all the disciplines towards the solution of a real challenge. It is interesting to link the results of Fig. 3 with the results of the survey applied to the students to evaluate the perception of the class towards the professor and the learning experience.

The student perception of the TU and the evaluation of the professor by the students is measured using a survey. The survey is applied to the students during the final week of the TU. It contains six questions that must be rated between 0–10, with being 0 the lowest score and 10 being the highest. Five of the six questions rate the lecturer's performance during the TU, including aspects such as experience, knowledge, and creating a respectful environment in the classroom. One extra open-ended question for comments is included. These aspects might not be directly related to the investigation reported here. However, question number five is interesting to this investigation as it evaluates the student's learning experience during the TU. Question five exactly reads: "*In general my learning experience with the professor was:*".

As the learning experience goes together with the perception of the student towards the methodology and considering that it is the same professor who is being evaluated with this question in the three analyzed TUs, question five provides insights into the perception of the students towards the method.

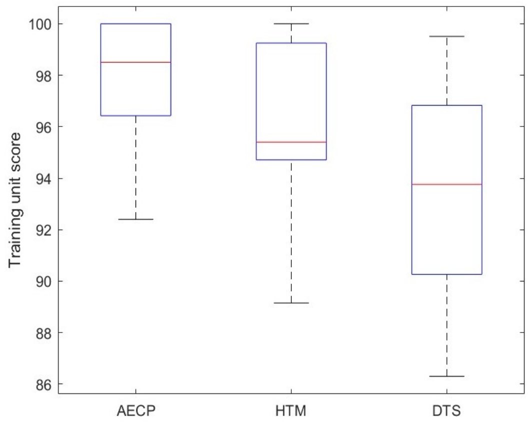

Fig. 3. Training unit score statistics.

Table I shows the score of question five for the three TUs. It can be observed that the results are quite similar, and students, in general, show no preference for the learning experience. Nevertheless, it can be observed that there is also no preference in this perception towards one approach or another related to the learning experience, even though the score in the final grade was lower with the multidisciplinary approach. This reflects that in this approach, successful performance in solving the challenge is a big motivation for the student rather than the numerical grade, and this has an impact on the survey applied.

TABLE I. SURVEY SCORES: STUDENTS EVALUATING THE LEARNING EXPERIENCE WITH THE PROFESSOR

TU	Students	Opinions	Score	Std. deviation
AECP	27	24	9.83	0.47
HTM	26	26	9.85	0.46
DTS	27	27	9.85	0.36

The results show a small difference with the highest score for the interdisciplinary approach with 100% participation and a slightly lower standard deviation. Students appreciate the learning experience slightly better with the same professor during the interdisciplinary approach. Finally, the open question in the survey reads: *"What would be your comment to anyone who is interested in registering for the training unit?"*. It was no identified negative comments in all the groups related to the difference in the method, implying that students feel comfortable with both the classical learning approach and the non-conventional interdisciplinary approach.

IV. CONCLUSION

An interdisciplinary approach, applied in a block TU involving CBL, was implemented in parallel with a traditional subject approach, to deliver content regarding thermodynamics, heat transfer, and fluid mechanics in a mechanical engineering program. The results in the academic performance in the theoretical modules showed no big differences using the two approaches. The results suggest that theoretical content related to different thermal sciences can be taught in an interdisciplinary fashion with no impact on the student's academic performance. The scores of the final grade of the TUs only showed slight differences. The lowest performance was observed in the block TU. This suggests that an interdisciplinary CBL block approach is more challenging than a subject approach. However, it can be concluded that nevertheless the challenge to the students in the interdisciplinary approach, the appreciation towards the learning experience is still high in this approach. It is true that the survey is filled by the students before they learn the final grade of the TU. The institution does not apply a second survey after the final grade is registered and shared with the student to avoid biased feedback. However, the conclusion of high appreciation towards the interdisciplinary approach is still valid considering that one of the main characteristics of this educational model is the continuous feedback to the student about his performance during the solution of the challenge. Before the student filled out the survey, different evaluations and feedback sessions occurred. The students are aware of their performance before obtaining the final grade. This conclusion is an important remark for the interdisciplinary approach since one of the main challenges in the learning experience is to maintain the motivation and interest of the student in the learning experience and not in the final grade of the learning process. Using interdisciplinarity broads the possibilities in the learning experience since the students focus on relevant matters such as competence development and leaving behind the grade.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

A.G.-C. implemented the experiment and the educational innovation. C.R.V. and M.N.-G. analyzed and discussed the results. All the authors participated in the elaboration of the manuscript. All authors approved of the final version.

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