A CASE-BASED LEARNING METHODOLOGY FOR THE STUDY OF THERMODYNAMIC CYCLES: APPLIED THERMODYNAMIC ASSIGNMENTS USING MICROSOFT EXCEL

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INTRODUCTION

Methodologies that enable self-directed learning and promote progressive study through challenges have proven to be successful [1]–[4]. Among these, project-based methodologies [3], [5]–[7] and case-based methodologies have demonstrated effectiveness in achieving the learning goals proposed for the courses [8]–[10]. In particular, case-based methodology is interesting because it allows the integration of topics included in courses taught with other components of the Bachelor of Science (BSc) in Chemical Engineering degree programs that are relevant to the future professional development of the students. Moreover, unlike open-ended or minimally guided approaches, this methodology ensures structured engagement with complex engineering scenarios, making it especially suitable for intermediate-level students who are still consolidating technical and analytical competencies.

Our university has implemented the case-based methodology in its BSc Chemical Engineering programs in the form of problem-generators presented as Jupyter Notebooks® (coded in Python™) or applications (programmed in MATLAB®), which allow student self-learning [9], [10]. In this work the type of case-based methodology was the directed-type one, a case-based learning methodology, according to its characteristics as lecture-based, directed, interrupted, jigsaw, and problem-based learning (PBL) [8]. This methodology can also address the specific concerns and skills of Generation Z students. These include characteristics such as open-mindedness, responsibility, determination (in achieving objectives), engagement with social issues, and caring behavior [11], [12].

Complementing this methodology, Microsoft®(MS) Excel® is one of the most widely utilized tools in the teaching of chemical engineering. It was applied in chemical engineering core courses using Excel Visual Basic for Applications (VBA), which was effective in teaching both simulation and optimization problems [13], [14]. Additionally, the MS Excel Solver was employed to address a range of optimization challenges within the BSc degree in Chemical Engineering [15], [16]. Furthermore, MS Excel has been instrumental in the creation of educational tools designed to facilitate the learning of ideal chemical reactor design [17]. Given these applications, MS Excel is undoubtedly a highly suitable platform for implementing a case-based learning methodology in the context of chemical engineering education.

This integrated approach was applied in the Applied Thermodynamics course within the BSc degree in the Chemical Engineering undergraduate program at Complutense University of Madrid (UCM), which is a compulsory course worth six European Credit Transfer and Accumulation System (ECTS) credits. This course is offered during the spring semester of the sophomore academic year. One of the course blocks, worth three ECTS credits, specifically focuses on thermodynamic power and refrigeration cycles. Teaching experiences within this block have been carried out with positive feedback from students. Educational applications were developed as problem-generators, designed to provide students with an "unlimited" number of exercises like those presented during the lectures: standard academic exercises on typical power and refrigeration thermodynamics cycles [10].

Encouraged by the positive feedback from these teaching experiences, the course instructors implemented a case-based learning methodology based on assignments that included increasing difficulty cases: from standard academic cases, like those included in our previous work, to more complicated cases based on research/real cycles. The course incorporated interconnected concepts taught in other courses such as the economic evaluation of a chemical process (introduced during their first year), as well as engaging topics, such as the environmental impact of chemical engineering processes and climate-related issues (including Global Warming Potential (GWP) and Ozone Depletion Potential (ODP) of refrigerants in multi-objective optimization — concepts that are part of other courses such as Climate Change and Environmental Engineering), trying to increase in this way the students' engagement with the course.

The main goal of this work is to apply a case-based teaching approach for the design of assignments that could enhance the understanding of thermodynamic power and refrigeration cycles and improve the engagement of students in the Applied Thermodynamics course offered as part of the BSc degree in Chemical Engineering at UCM. This work was reviewed locally by the appropriate board and did not meet the definition of research. This methodology aims to facilitate students in demonstrating acquired knowledge via solving proposed case studies that gradually increase in difficulty. Concurrently, it seeks, as secondary objectives, to arouse students' interest by establishing interconnections between courses offered throughout the program, strengthening competencies more closely aligned with professional performance, and addressing contemporary issues that interest Generation Z, including environmental and social concerns such as climate change and sustainability [18], [19].

RESEARCH DESIGN

Employed Software: MS Excel and CoolProp Packages

The software selected for solving the assigned cases is crucial, as it must meet specific requirements. It should be licensed by the UCM or free for use, commonly used by students, and/or they must have received prior training on it. The software must be user friendly, as the purpose of the cases is the study of thermodynamic cycles, and the chosen software should not add difficulty outside the course objectives. The available software that could be used is extensive, ranging from programming languages like MATLAB, Wolfram Mathematica®, or Python, previously used in the literature [20]–[26], to commonly used general-purpose software such as MS Excel, LibreOffice, Google Sheets®, and others. The utilization of process simulators such as ChemCAD™, Aspen Plus® or DWSIM, used in thermodynamics courses for chemical engineering students [27], [28], was dismissed since our students will not receive training/courses on these software tools until their junior year.

Under these requirements, the two software options that met the established criteria were MATLAB and MS Excel, both widely known in the academic and professional engineering fields. BSc Chemical Engineering students receive prior training in both through the compulsory Applied Computer Science course taught during their first year fall term and are licensed by the UCM. However, their single utilization is insufficient since they do not allow the straightforward calculation of the thermodynamic properties of the working fluids used in power and refrigeration thermodynamic cycles. Thus, the CoolProp package presented a suitable choice to complement our approach due to its open-source and cost-free nature, distinguishing it from other common properties software libraries like REFPROP [29]. Additionally, its compatibility with the two previously selected software tools, MATLAB and MS Excel, further justifies its usage. In the case of MS Excel, the installation of CoolProp as an add-in is a simple process. In addition, CoolProp has comprehensive documentation available online, which includes scientific literature references supporting the equations of state (EOS) and the thermodynamic methods employed to determine the properties of the available working fluids. The instructors of the course used this documentation to develop help applications for students.

Ultimately, MS Excel was chosen over the other options because it provided additional features of great interest that facilitated its use compared to MATLAB:

- The CoolProp package for MATLAB has been outdated for years, and the MATLAB wrapper is now unsupported. As a result, its usage is suggested only within the MATLAB environment under Python, where it is still being developed.
- MS Excel allows a better and easier delivery organization through spreadsheets for each of the proposed cases within the same workbook (which contains each assignment) and the inclusion of the questionnaires in said spreadsheets.
- Creating templates for each case is much easier in MS Excel, which simplifies both the instructions for solving the cases and the evaluation of the results delivered by the students (in a practically automatic way).

Course Syllabus and Learning Outcomes

The course syllabus is based on the classic applied thermodynamics textbook by Moran et al. [30] The block of the syllabus dedicated to thermodynamic cycles covers the teaching on the determination of thermodynamic properties, with a focus on water and steam, but extendable to other working fluids. The block also includes exergetic analysis of systems and the teaching of steam power cycles such as the Rankine cycle, improved Rankine cycles, and cogeneration systems, as well as gas power cycles (Brayton and modified Brayton cycles) and combined gas-vapor power cycles. Also, vapor-compression, gas, and absorption refrigeration cycles are covered in the syllabus. The key learning outcomes of the syllabus are:

1. Determine the thermodynamic properties of steam, gases, and refrigerants
2. Discuss the fundamental principles of steam and gas power plants, as well as refrigeration systems
3. Design, analyze, and optimize thermodynamic power and refrigeration cycles through:
    - Sketching and understanding T-s, p-h, and p-v diagrams for thermodynamic cycles
    - Calculating thermodynamic properties for the states of the cycles
    - Applying mass and energy balances for thermodynamic cycles
    - Determining the performance of thermodynamic cycles: thermal efficiency, exergetic efficiency, and COP (coefficient of performance)
    - Optimizing thermodynamic cycles according to thermal efficiency/COP, economics, and environmental criteria

Assignment Design

The methodology proposed in this work is a case-based approach that was developed through assignments with clear and structured assessments and involves a lecture-based/directed format, i.e., the students receive a MS Excel template as ready-made material. This method requires limited student autonomy since all cases are fully described and all necessary data are provided [8], [31]. Each of the two assignments, focused on power and refrigeration cycles, must be submitted by the students during the thermodynamic cycles course block. The assignments consist of cases and must be completed within 15 business days. This submission window is set to accommodate students who are balancing jobs or other commitments, providing flexibility in scheduling the work. Moreover, to address diversity, equity, and inclusion, the assignment instructions are created using a LaTeX template that allows for customization of font size and color contrast: it includes actions such as a help button in the PDF linked to audio and visibility options for publishing (PDF format): e.g., color blind and low visibility options that change the colors of the built PDF, etc. This approach supports students with visual impairments and specific readability preferences.

In each assignment, a Base Case similar to the exercises solved in the classroom was presented, followed by cases, typically three or four per assignment. These cases incorporated elements of the base thermodynamic cycle and progressively increased the difficulty in the resolution of the exercises. Additionally, they approximated the given cases to more realistic cycles, as the Base Case was generally an ideal thermodynamic cycle. In this way, students can enhance their skills as they advance in solving the tasks and analyze the suitability and reliability of the assumptions made in the ideal thermodynamic cycle based on the results achieved in the subsequent cases. Each assignment's cases were arranged in a sequence of spreadsheets within an MS Excel workbook. Additionally, the first sheet of workbooks included questionnaires pertaining to the theoretical background necessary for comprehending and resolving the cases. Furthermore, the workbooks also contained questionnaires aimed at evaluating the students' capabilities after resolving the cases. These questionnaires inquired about the acquired knowledge and obtained results.

Regarding the learning objectives of the assignments and the case-based methodology, each assignment includes clear instructions that fully describe the cases and provide references to solve the cases. These details aid students in conceptualizing the assignments. Each case includes a process flow diagram of the thermodynamic cycle in the spreadsheet as a guide for the students to interpret and analyze. The presented cases increase in difficulty to incorporate knowledge/skill-based achievements in the proposed methodology while also facilitating engagement in analogical reasoning through the comparison of ideal and real cases. The case-based methodology also allowed the introduction of new thermodynamic content, such as the study of organic Rankine cycles and cryogenic cycles for liquefaction of gases. Finally, the spreadsheets also covered the study of other essential concepts in chemical engineering, such as economic implications of the process, sensitivity analysis of the cycle, selection of the fluid used in the process (not included in the example shown in the results section), particularly in refrigeration cycles (as an introduction to the study of discrete variables). In addition, students were asked to optimize the cycles based on a thermodynamic variable, such as thermal efficiency, the Coefficient of Performance, or economy of the process. This was meant to improve the engagement of students by increasing their motivation and satisfaction with learnings in the assignments since these concepts should awaken their curiosity and link the cases to real life and Generation Z concerns.

RESULTS

Assignments and Cases

During the past three academic years, the instructors have created a series of 8-10 different assignments. This section provides an example of one of these assignments to show its structure and content. Figure 1 shows an assignment completed during the academic year 2022-2023, which involved resolving an Organic Rankine cycle. The instructions spreadsheet and Base Case are shown in Figure 1. The Base Case used in this assignment was adapted from the work of Méndez-Cruz et al. [32]. The selection of a scientific article serves a triple purpose: introducing students to the use of scientific literature, arousing their interest in scientific work, and motivating them to solve a problem based on a realistic case.

The instructions spreadsheet (Figure 1a) shows the document, (also available in PDF format by contacting jucdomin@ucm.es) provides students with a detailed description of the cases included in the assignment, including a process diagram, references, operating conditions, equations, and a description of the cycle parameters; and includes instructions on how to perform the calculations required to achieve the results necessary to solve the cases. Figure 1b shows the spreadsheet template created for solving the Base Case. As with any case, the spreadsheet contains a process flow diagram (PFD) of the cycle with labeled cycle units and numbered streams. The template is devoid of values, so students must input the values provided in each case statement (from the operating conditions table). This design aims to enhance students' knowledge and understanding of the cycle, ultimately improving their exam performance. The template contains a table in which students were required to calculate the thermodynamic properties of each state of the cycle using as inputs either operating conditions or previous calculated properties/states (the students had to use PropsSI, a function provided by the CoolProp add-in for MS Excel similar to MS Excel built-in functions), including ideal states (considering isentropic processes). Any unknown properties had to be determined using CoolProp in the spreadsheet and could not be entered as values. This was not critical in the Base Case, but it was important for further cases where maximum and minimum values were calculated using MS Excel Solver since they were decision variables in the optimization cases. In the cycle analysis results table, the students used thermodynamic properties of the cycles to determine mass and heat flowrates, power of the pump and the turbine, specific steam consumption, entropy generated in the different units of the cycle, and thermal and exergetic efficiency of the cycle. The template follows the same structure as exam problems. Since the 2021-2022 academic year, students take their midterm and final exams in a computer room, where they have access to the Moodle™ course (with all the PPT presentations of the course), the internet (but they cannot communicate with anybody), and solve part, or sometimes all, of the exam problems using MS Excel. Therefore, the assignments serve as a good test not only of their knowledge but also of their ability to solve problems using MS Excel and CoolProp.

Figure 1 shows the structure of the assignment in each of the tabs corresponding to the spreadsheets of the MS Excel workbook. The tabs include instructions, CoolProp functions, academic integrity declaration, the cases (three in the example shown), a questionnaire, and a spreadsheet where students can check the evaluation criteria of the assignment. The spreadsheet of CoolProp functions contains a summary of the PropsSI function, which is installed as an MS Excel add-in and used to determine thermodynamic properties. The function's syntax examples are included, and it can be accessed through an on-screen menu like native MS Excel functions, making it easy to use. The academic integrity declaration is a template document that students must fill out, print, and submit to instructors. The students were informed of the consequences of submitting plagiarized work and agreed not to do so.

Figure 2 shows the template for Case B. This case, which is an extension of the initial case, requires the use of MS Excel Solver to calculate the maximum values of the parameters used in the multivariate optimization of the cycle within certain constraints.

Figure 2a shows the main tables, which are similar to the Base Case, and the PFD of Case B. To simplify the task, students can copy and paste the cells that were entered or calculated in the previous case, as the cycle is the same for all the cases. This assignment differs from others in which the cycles were changed/improved from an ideal Base Case, with increasing difficulty in subsequent cases due to changes in the thermodynamic cycle. The challenge in Case B was to identify the maximum parameter values, which were then used to optimize the cycle in subsequent cases. Therefore, the students used MS Excel Solver to solve this case, as they had a compulsory course on MS Excel and MATLAB in the first semester of their first year. Case B was helpful in teaching the students how different variables, including operating conditions, can affect a cycle's performance. They were able to identify trends and discuss the constraints of the cycle, such as their physical meaning and how they could impact the results. Moreover, this case provided an opportunity to acquire or refresh transversal competences, such as critical thinking. The students were advised to exercise caution with possible local solutions when dealing with mathematical competencies. They were instructed to check if their results depended on the initial values entered before running the solver. In terms of computing competencies, the students had the option to

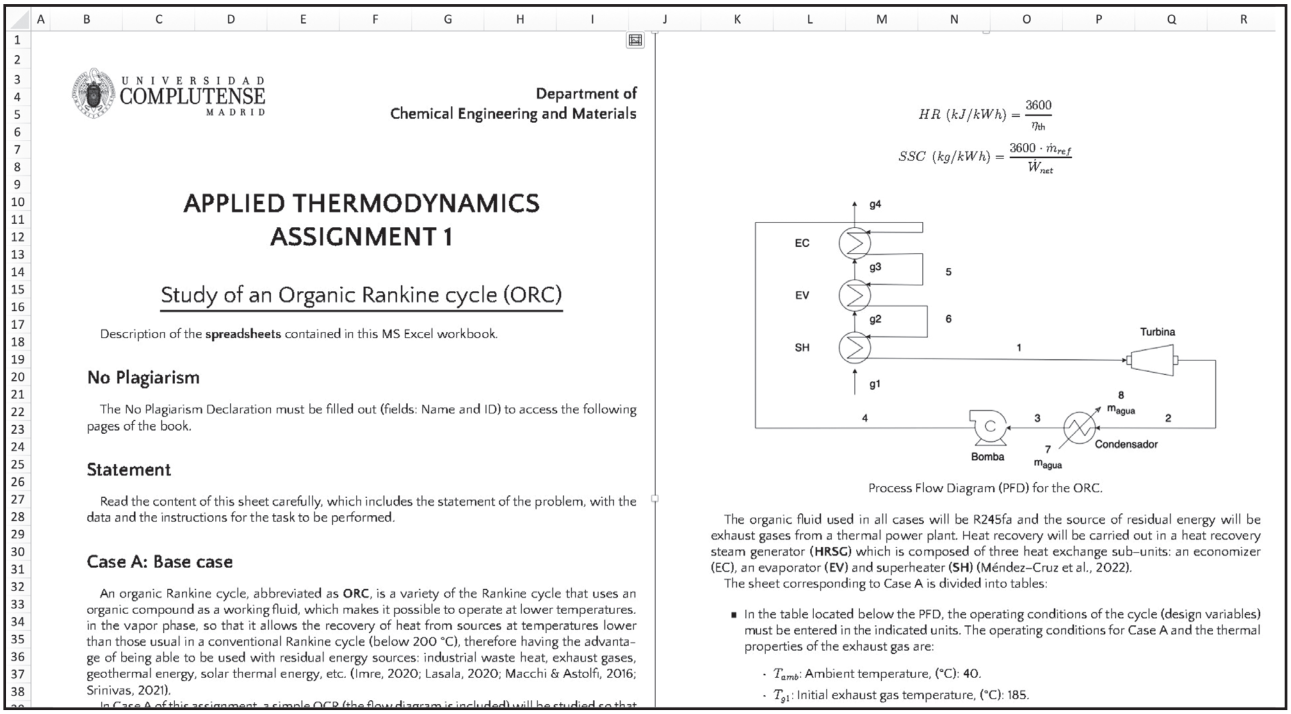

Figure 1a

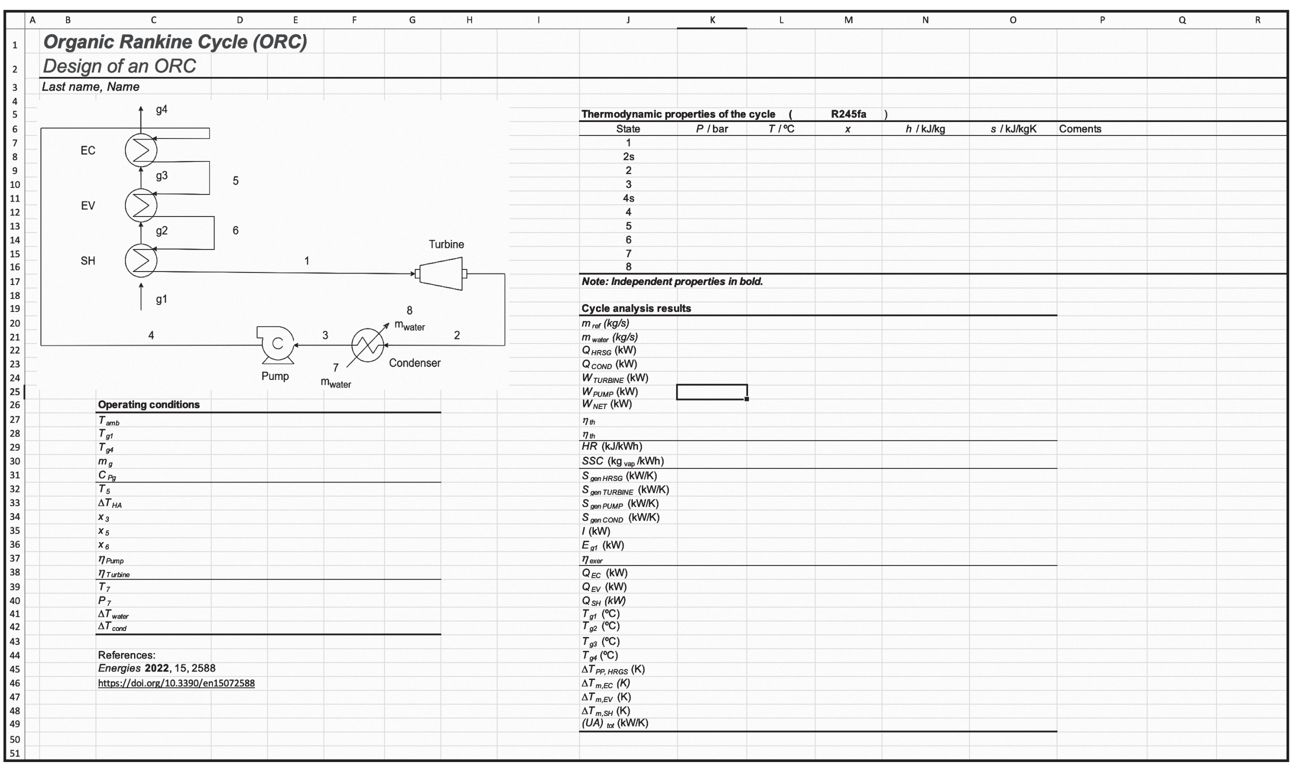

Figure 1b

Figure 1. *Example of a power cycle assignment using an MS Excel template. (a) Instructions sheet of the workbook; (b) Base Case sheet containing the diagram of the cycle and tables (cells) for entering the operating conditions and calculating the states and results of the cycle.*

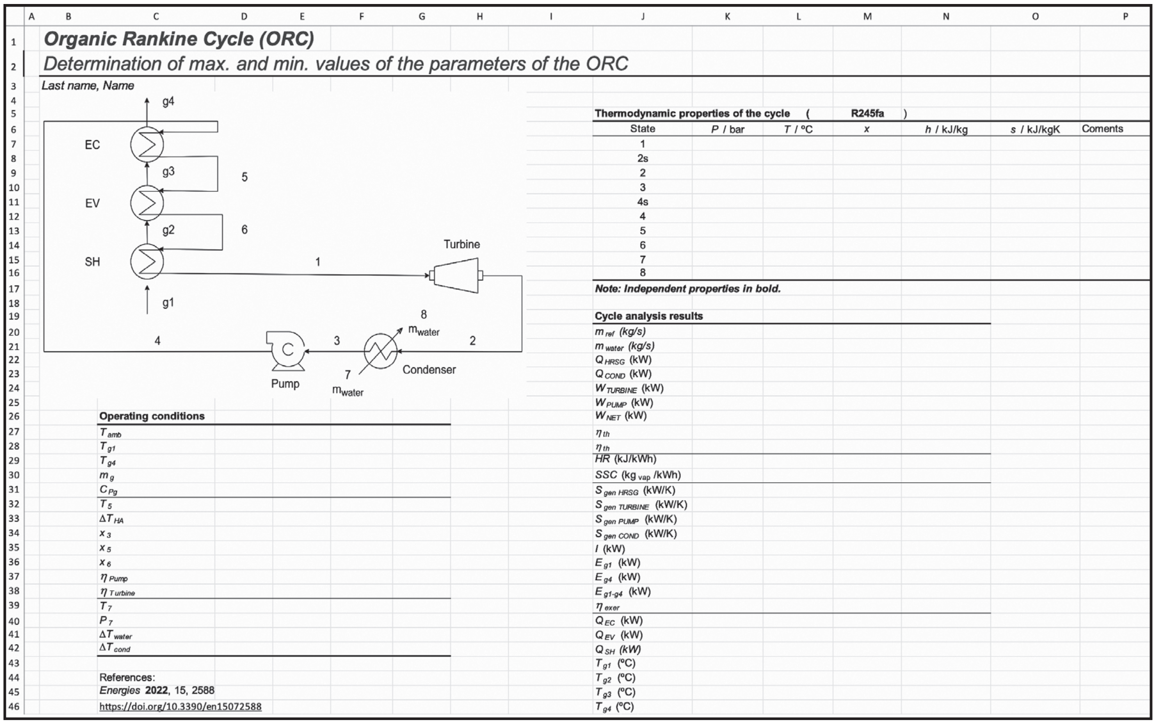

Figure 2a

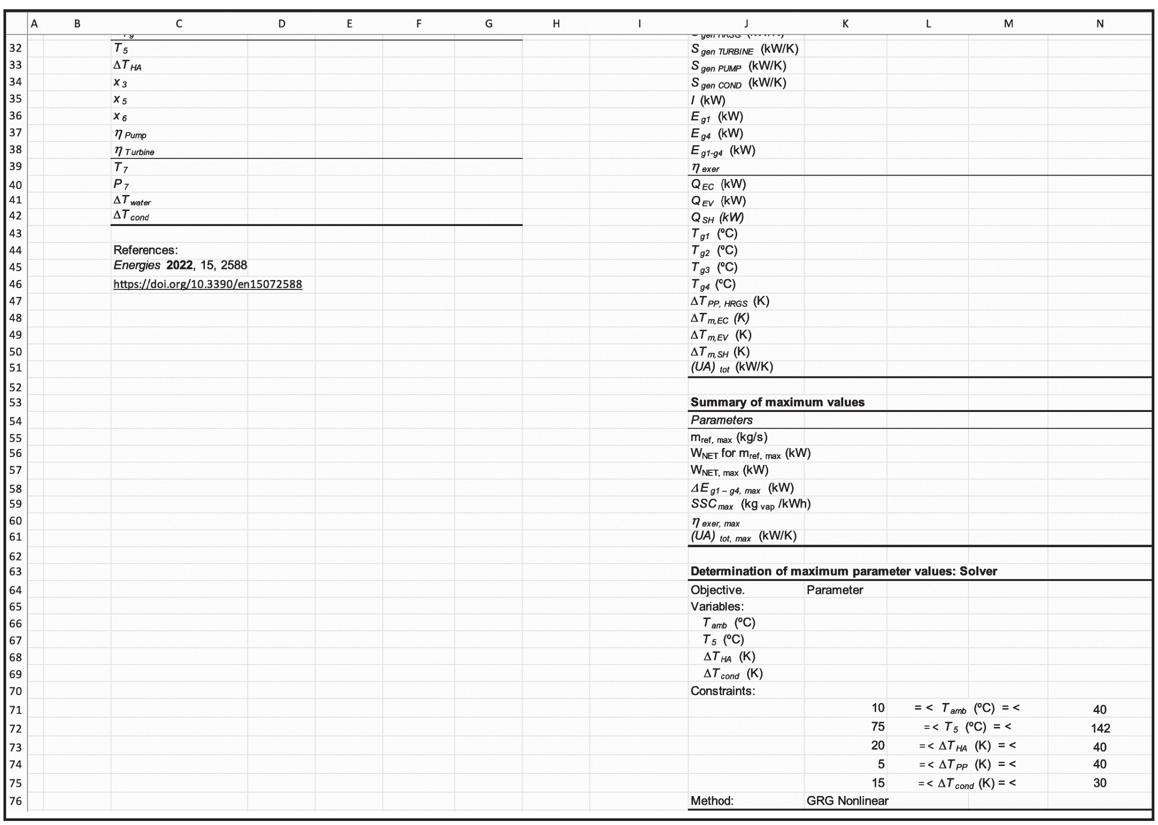

Figure 2b

***Figure 2**. Case B of the assignment. (a) main tables (same as the Base Case); (b) cells where the different parameters must be maximized changing the indicated variables of the cycle within the included constraints and summarizing table.*

use a method other than the recommended GRG Nonlinear in the MS Solver to find global maxima. They could also select suitable initial values before running GRG Nonlinear and/or run the Solver under a hybrid method.

Figure 3 shows the cells of Case C that are relevant to the main objective of this case, which is to determine the optimal operating conditions of the cycle through a multivariate optimization that considers environmental aspects (GWP and ODP).

The main objective of Case C was to determine the optimal operating conditions of the cycle through a multivariate analysis. To achieve this, the students used the results obtained in Case B to normalize all the parameters considered in optimizing the cycle. The values of the specific weights of each of the parameters were given in the instructions of the assignment, indicating that the objective function is normalized between 0 and 1 due to the normalizing of the parameters and the sum of their specific weights. By resolving this case, the students could understand the different possibilities when optimizing a process and how to weigh them appropriately. In this instance, the cycle was optimized by considering energy parameters, such as efficiencies and energy integration of the process (a pinch analysis was not carried out, but the concept of pinch point was included, its value being one of the factors included in multi-objective optimization), exergy (maximum use of the available energy in the process), and environmental factors, such as the ODP and the GWP of the organic fluid.

	J	K	L	M	N	O
52						
53	**Summary of maximum values**					
54	*Parameters*					
55	$m_{ref,\ max}$ (kg/s)					
56	W_{NET} for $m_{ref,\ max}$ (kW)					
57	$W_{NET,\ max}$ (kW)					
58	$\Delta E_{g1-g4,\ max}$ (kW)					
59	SSC_{max} (kg_{vap} /kWh)					
60	$\eta_{exer,\ max}$					
61	$(UA)_{tot,\ max}$ (kW/K)					
62						
63	**Determination of maximum parameter values: Solver**					
64	Objective	0,0000	$= \Sigma (\alpha_i \cdot \omega_i)$			
65			α_i		ω_i	$\alpha_i \cdot \omega_i$
66			W_{NET}		0,14	0,0000
67			ΔT_{PP}	0,0000	0,14	0,0000
68			ΔE_{g1-g4}		0,14	0,0000
69			SSC		0,14	0,0000
70			η_{exer}		0,14	0,0000
71			$(UA)_{tot}$		0,14	0,0000
72			GWP		0,11	0,0000
73			ODP		0,05	0,0000
74	Variables:					
75	T_{amb} (ºC)					
76	T_5 (ºC)					
77	ΔT_{HA} (K)					
78	ΔT_{cond} (K)					
79	Constraints:					
80		10	$=< T_{amb}$ (ºC) $=<$		40	
81		75	$=< T_5$ (ºC) $=<$		142	
82		20	$=< \Delta T_{HA}$ (K) $=<$		40	
83		5	$=< \Delta T_{PP}$ (K) $=<$		40	
84		15	$=< \Delta T_{cond}$ (K) $=<$		30	
85	Method:	Evolutionary				

Figure 3. *Case C of the assignment. Cells with the specific weight of each optimization parameter, their calculated contribution (after being normalized using the results of Case B), and the value of the objective function, which must be maximized using the Solver.*

The students were initially informed that the selection of the organic fluid was not considered among the modifiable variables for optimizing the process. However, the reference article on which the assignment was based indicated that it was a variable to be considered, as it affects the operating conditions and environmental impact of the cycle. The resolution achieved secondary objectives, such as informing that the optimization of processes may require consideration of discontinuous responses or variables. The parameter related to the pinch point was defined using a discontinuous function, with a constant value fixed for different intervals. The definition of the parameter is included in the assignment instructions as supplementary material. The method for resolving the case was determined by the situation. The students were instructed to use the Evolutionary method from the options available in the MS Excel Solver.

Finally, the students of the course were challenged to respond to a questionnaire. The students were presented with questions pertaining to the resolution of the assignment cases. Answering these questions required a thorough understanding of the concepts introduced in the assignment and the ability to discuss them. The following questions were asked in the example:

1. For Case C, the "Evolutionary" method is used instead of "GRG Nonlinear," which is used in Case B. This change was made because the objective function presents discontinuities. Please explain the reason for this change.
2. Discuss the interest of Organic Rankine cycles with respect to the traditional Rankine cycle, based on the literature and p-H thermodynamic diagrams. Also, mention other fluids used in these cycles in addition to R245fa. What properties and advantages do they have compared to water?
3. To ensure proper operation in the condenser, there must be at temperature difference of at least 5 ºC between the outlet stream of the cold fluid and that of the working fluid of the ORC cycle. Do you consider that it is a restriction that must be implemented in the simulation or that, indirectly, it is already imposed? Please provide a reason for your answer.
4. Do you consider that the environmental parameters taken into account in the optimization significantly contribute to the cycle's optimization?

During the lectures, the students were instructed on how to explain the assignment to facilitate answering the questions. For instance, they were given tips on using optimization methods and justifying their selection. Additionally, they were advised to attempt reducing the specific weight of the environmental parameters for question 4 and observe its impact on the optimization result.

Figure 4 shows the evaluation criteria for the assignments in the last spreadsheet of the workbook. The score of the thermodynamic properties item is the sum of the number of states that they calculated correctly; the results item is related to the heat, work, mass flow-rates, and efficiencies of the cycle; the item Summary of max. values is linked to the single-objective optimization of each factor considered in the multi-objective optimization; the Definition of the objective function is linked to a single cell, where the students have to implement the function considering all the factors and their weights; and the calculated optimal value is the result of the multi-objective optimization. This allows students to see the score for each case and question in the assignment.

Figure 4 shows that students only needed to correctly solve the Base Case to earn the minimum score for a grade D (the numerical grading system used at UCM can be found at https://www.ucm.es/english/grading-system). As they solved the cases, the difficulty increased sequentially, but the score gain was reduced. This evaluation system allowed higher performing students to be rewarded without disadvantaging others. It was relatively easy to achieve a passing score, but obtaining a high score was more challenging. The points assigned to the questions could be obtained through a theoretical analysis of the cases, following the previous explanations of the instructors in the lecture dedicated to each assignment. However, the resolution of the cases significantly facilitated the answering of the questions, something that was indicated to the students.

Organic Rankine Cycle (ORC)

Score

Last name, Name

Evaluation criteria		Score
1. Case A		5,00
Thermodynamic properties	3,00	
Results	2,00	
2. Case B		1,50
Results	0,50	
Summary of the max. values	1,00	
3. Case C		1,50
Definition fo the objective function	1,00	
Calculated optimal value	0,50	
Questions		2,00
Global score		**10,00**

Figure 4. Assignment scoring table.

Student Survey and Scores

A survey was distributed to the students by the instructors, ensuring that responses remained anonymous using a standard procedure. The survey questions, which were derived from previous studies [9], [10], [33], are shown in Table 1. The questions are divided into three blocks. The first block, (Q1-3), focuses on the use of MS Excel workbooks for displaying and solving assignments. The second block, (Q4-10), contains questions about the assignment's content, difficulty, and design. Finally, the third block, (Q11-12), asks participants to evaluate the work of the instructors and state their interest in using the same case-based methodology in future courses. However, the results shown are not intended to be part of an in-depth statistical analysis, but rather merely indicative of trends that, along with other factors that are difficult to measure, can inform instructors about the level of acceptance and success of the methodology, as well as possible future improvements.

The findings of the survey, conducted during the academic year 2022-2023 and involving 54 students enrolled in the course Applied Thermodynamics, are shown in Figure 5.

The first two questions of block 1 of the survey received positive feedback, with 54% and 87% of respondents answering affirmatively, respectively. Only a negligible number of students were neutral in their answers to these questions. The instructors attribute this to the detailed guidelines included for each task and the use of MS Excel as the designated software for case study solutions. Additionally, first-year students are required to take a compulsory Applied Computing course during their fall semester, which further justifies the instructor's reasoning. Furthermore, the convenience of using CoolProp via MS Excel was a deciding factor, as its integration as a native function with a user-friendly menu. This effectively resolves the issues encountered in previous works when utilizing Jupyter Notebook for similar endeavors [9]. With regards to question 3, the students expressed a marginally negative viewpoint, 16% more unfavorable than favorable. This outcome is attributed to the fact that the most challenging assignments in recent years necessitated the use of the Excel Solver, with which the students previously had limited familiarity. To address this potential hurdle, they were supplied with a bibliography to facilitate learning and attended a lecture solely focused on the use of Solver to tackle the proposed assignment problems.

Block 2 of the survey, which includes questions 4 to 10, aims to evaluate the degree of satisfaction of students related to the assignment's content, difficulty, and design of the case-based learning teaching methodology. For questions 6 and 9, the class was divided in its response; 50% of students provided a positive response, affirming that the available timeframe of 15 days was adequate for completing the assignments and that this task had enhanced their

TABLE 1 Questions Included in the Survey	
Question 1	The assignment guidelines and template were straightforward and comprehensible.
Question 2	The use of the CoolProp package in MS Excel was not complicated.
Question 3	The utilization of MS Excel to complete the assignments was easy.
Question 4	The assignments enhanced my understanding of the course and developed my skills in problem-solving.
Question 5	The complexity of the assignments correlates with the explanations and instructions provided by the instructors.
Question 6	The complexity of the tasks aligns with the allocated time.
Question 7	The utilization of these tools has enhanced my academic performance.
Question 8	The implementation of case-based assignments presents an advancement over conventional teaching methods.
Question 9	The specified assignments have honed my skills beyond the scope of the course.
Question 10	The assignments' content aligns the course's competencies with those already or will be received throughout the degree and future professional pursuits.
Question 11	I aim to implement assignments and evaluations based on a case-based teaching methodology in upcoming courses.
Question 12	What is your assessment of the instructors' dedication in crafting the assignments using this methodology?

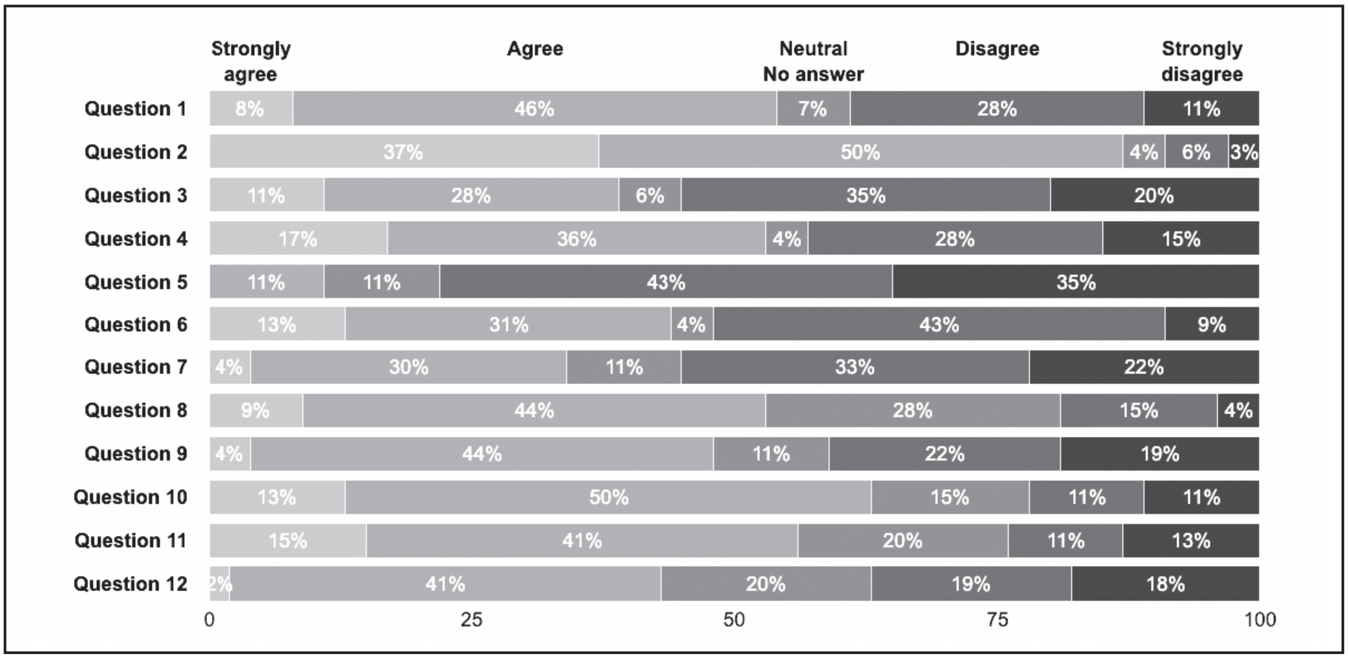

Figure 5. *Results of the survey on the assignments. From light, positive responses of students, to dark.*

proficiency in thermodynamics problem-solving. Conversely, the remaining fifty percent did not support this claim. The instructors consider it important to note that, in most cases, students posed questions about the assignments only two days before the deadline. This pattern suggests that students may not fully utilize the extended and flexible time frame provided for completing the assignments. Therefore, according to them, a contributing factor for the insufficient time to complete the task may be that many students initiate working on the assignments perilously close to submitting them. Overall, the students rated the case-based methodology positively compared to other methods they have used before (Question 8). However, for this specific question, the results indicated that the largest portion of students either felt neutral or did not want to express their opinion (28% neutral). Regarding question 10, 63% of the students gave a positive rating to the objective of linking the competences of the Applied Thermodynamics course with other elements of the Chemical Engineering degree program, as intended by the instructors. This approach has been successfully implemented in other courses and has also been well received by students. Based on responses to question 5, the assignments were deemed weak due to instructors providing explanations and information that were above the students' proficiency level (78% agreement). The instructors also believe that the students used limited literature in their assignments. It is often the case in other courses that students only use the provided literature citations when a document is given directly to them or do not consult the literature at all. One potential resolution to this issue could involve delivering the lecture following the task's release. This would give students the opportunity to ask questions after working on the assignment, as well as to receive additional clarification. Finally, the response to question 7 also showed a slightly negative opinion (55%). The percentage is not significantly concerning, and the expressed viewpoint appears somewhat contradictory when examining responses to questions 4 and 9. Nonetheless, the instructors aim to encourage students to enhance their optimistic outlook in this regard, as completing the assignments has been shown to improve academic performance, resulting in higher grades.

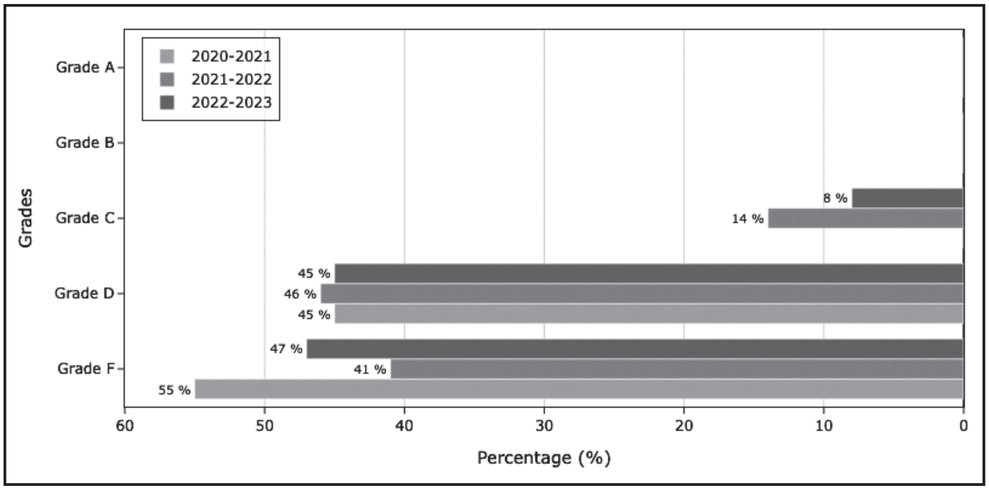

Figure 6. *Final grades distribution for the three courses where the methodology was implemented.*

Finally, based on their answers to the two questions in block 3 of the survey, the students expressed their interest in the case-based learning approach integrated into the course assignments. They also acknowledged the instructors' efforts in preparing them.

The impact of the case-based methodology on academic outcomes was examined beginning in the 2020-2021 academic year, which marked the inception of this methodology as a component of the course evaluation. The impact of the methodology was evaluated by how this methodology affected final grades in the course. Figure 6 shows the resulting grades of the courses.

The total number of participants registered in the course was 97, 116, and 124 for the courses 2020-2021, 2021-2022, and 2022-2023, respectively. The analysis of the grade distribution did not reveal any significant difference between the academic years 2021-2022 and 2022-2023. There was a small decrease in the percentage of Grade C, but the results were quite similar. However, there was a significant improvement in these courses compared to the initial course in which the case-based methodology was implemented (2020-2021). The number of students who passed the course increased from 45% (2020-2021) to 60% (2021-2022) and 53% (2022-2023), elevating the passing rate above 50%. Additionally, this increase in percentage was also reflected in a rise of C grades. The study revealed that an improvement in the assignment scores led to higher final grades and an increase in the number of students passing the course.

Further Work

Based on the obtained results and feedback from students and instructors, certain actions can be taken to achieve the stated objectives:

- Demonstrate to students that completing all the proposed cases in the assignments, rather than solely the Base Cases, which typically account for 40-50% of the total score, will substantially enhance their results in this course
- Show students the value of the knowledge gained from these cases is valuable for their academic and professional development
- Provide clarification on the assignments during the designated submission period to address any potential student uncertainties and effectively utilize the 15-day submission window
- Develop a set of concise instructional videos demonstrating the use of MS Excel for completing assignments. The exact number of videos required is yet to be determined, but the overarching goal is to enhance students' performance with MS Excel while still encouraging self-learning and adherence to the bibliography guidelines outlined in the instructions.
- Provide links to audiovisual material directly related to the assignments to allow students to connect with the cases presented and enhance their understanding.

This approach can improve their perspective, thereby increasing their enthusiasm for completing the assignments.

- Propose incorporating a project-based methodology into the current case-based approach for course assignments, enabling students to collaborate on a group project throughout the semester. The main challenge in implementing this approach is managing the large number of 55-70 students enrolled in the course.

- No students obtained A's or B's, which will be studied in depth to identify the raw causes and implement solutions.

CONCLUDING REMARKS

This study introduced a case-based learning approach for teaching thermodynamic power and refrigeration cycles with the aim to improve student performance, connect the course with broader Chemical Engineering concepts, and engage Generation Z students on the course by focusing on topics such as sustainability and climate change. Following the first year of adaptation to this new methodology, students showed improved academic performance, with more students achieving passing and higher grades. Furthermore, a clear link between the work completed throughout the coursework (both self-learning and personal work) and the final grades obtained in the class was found, as commonly commented by instructors at the beginning of the course. However, the proposed survey revealed that students do not recognize the connection between work completed and the final grade. Finally, the students gave a positive response to this methodology, and they would like the instructors to implement it in upcoming courses. They also evaluated very positively the approach of linking the course with other topics included in the program of the BSc degree. However, they require further lectures explaining the cases in detail; therefore, more actions are planned for further courses.

TEACHING MATERIALS AVAILABILITY

The MS Excel templates discussed in this manuscript will be willingly provided upon request. Please contact Prof. Juan Carlos Domínguez (jucdomin@ucm.es) at Complutense University of Madrid (Spain) to express interest. Furthermore, some of the materials can be downloaded from https://github.com/BIAPYP/Docencia.

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