TEACHING ENGINEERING THERMODYNAMICS IN A SMALL AND MEDIUM ENTERPRISE ENVIRONMENT

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Abstract. *Some insights are given on the method used in teaching Thermodynamics in a one semester bachelor's mechanical engineering and industrial management course. The fact that a professional degree is attained within a 3 year long graduation, which introduces the same sort of trend as the Bologna's Declaration on the European Space for Higher Education, forces teaching an usually straightforward structuring chair with a different approach, needing to encompass basic engineering concepts with some adequately chosen applications. Moreover, surveys indicated that a great majority of graduates were working in medium and small enterprises, displacing focus from conception to management of thermal equipment and plants. A description of the measures undertaken, as well as some of the results obtained, is given.*

Keywords. *Engineering education, Thermodynamics, Technology*

1. Introduction

The Polytechnic of Viseu is located in the upper part of Portugal, in a zone where the industrial environment is closely linked to the region resources, namely wood and forest, ornamental stones and thermalism/spas. The enterprises dimension is very much like the rest of the country, *i.e.*, in number of enterprises, 80% are small and medium dimension organizations. Nevertheless, those are responsible for almost 90% of the workplaces. Their level of R&D is low, only around 15% of that budget being financed by the private sector. Though important to enterprises competitiveness, traditional research or development are thus not significant and several polls conducted by the institution has clearly shown that the great majority of graduate students perform structuring organizational and solving problems tasks within their organizations. And recognizing without fearing to overstress the importance of the use of basic physics and chemistry to understand new concepts and new applications to technology products still is not sufficient to allow individuals to adapt easily to the sort of environment awaiting them at the end of the formal academic career. Beyond product or system requirements to address customers needs and values, capability of effective time management to reduce costs and improve quality, establishing team goals, contributions and committed management, involved in the Industrial Management component of the graduation, areas concerning the core subjects of an engineering syllabus, such as Thermodynamics, also must adapt to the need to contribute to that applied feature graduates must possess. Especially when the global trend in European engineering education, through the joint declaration of Bologna (1999) where a process of creating a "European higher education area" by 2010 has been moving towards a first generalized first degree of three to four years, capable of endowing the industry with competent technicians and thinkers (Marques and Paiva, 2000).

2. The Thermodynamics course

Traditionally a difficult course, Thermodynamics is the core of significant number of engineering programs and, in a Mechanical Engineering graduation, tends to be a major cornerstone. An average of only 30-40% of students attending classes use to pass the grade on a first attempt. Or, maintaining higher student retention rates is important, and a high level of failure has definitely a negative impact on it, not only because of the country's need for technicians, in general, and engineers in particular, but also because higher education is a valuable resource no country can afford to waste. Taking a look at the available textbooks we find a somewhat uniform approach or organization of themes. We ourselves did not made any significant contribution to modernize this particular aspect as the course is divided in the following nine modules (Çengel and Boles, 2001):

1. Introduction, Concepts, Units and Definitions
2. Thermodynamic Properties
3. First Law for Closed Systems
4. First Law for Open Systems
5. Second Law and Entropy
6. Second Law for Closed Systems
7. Second Law for Open Systems
8. Power and Refrigeration Cycles
9. Gas Mixtures and Air Conditioning

The focus is directed not only to numerical values calculation, but to conceptual understanding keeping in mind linking problems with the entrepreneurial environment main issues and real problems solving, since students are in an 'engineering technology program', expecting to deal with how systems function and its relation to design and operating decisions (one class runs at the end of the day, to allow full-time jobs working students to attend it, and has been a strong support to this practical approaches). The ability to contact the professors was provided, either by mobile phone or email. It was used at the very beginning, as a startup activity, to post the course syllabus, topic schedule and homework assignments, increasing the student/teacher interaction (Bourne *et al.*, 1996).

3. Classroom work and activities

Lecture presentations are used to present factual material, to introduce theoretical concepts, to develop and present equations and to demonstrate some chosen problem solutions. An average of 50% of the time scheduled is used solving example problems, either by individual presentation, or for initial periods of problem solving workshops ending in one group setting out the complete resolution, answering to questions of the rest of the class. Also, students are given all or part of a problem to be solved, the professor quickly views the problem conceptual solution (especially if he feels that the students seemed to be struggling with the problem) with a particular group and this last one works on it thereafter and ultimately provides feedback to the class, either during course time, or by email. The professor take notes on team and individual member's performance, as it will represent a 20% surplus in the final grade, together with classes' attendance (which is, nonetheless, obligatory in order to be able to pass exams in the regular period of that semester- a minimum of 75% of class attendance is mandatory).

As to lab classes, they used to follow the traditional scheme of lab typical experiences concerning properties evaluation as the calculation of substances specific heat, studying water vapor evolution with pressure and temperature, performing mass, energy and entropy balances on models of houses, heat exchangers, central heating heaters and small scale refrigeration systems. After almost a decade has passed, there was increasing difficulties in avoiding copy/paste operations from precedent years, though the lab work required changed each time and the evaluation was thoroughly made (Mazur, 1997). Adding to this was the fact that, with increased number of students, there was a need to either increase the faculty number of hours for accompanying and supervising or multiply the number of setups for each subject at students' disposal, so that they can use it and perform simultaneously the addressed tasks. The first alternative would permanently load the budget and the second would require further hardware investments. Given that quite often there is a lack of facilities or budgets to purchase and maintain physical artifacts (such as power plants, jet engines, and refrigerators) for students to experiment with and that faculty members, in the public service, is doomed to reductions, neither of them was in phase with the actual context of the educational system constraints. Furthermore, there was a strong impression that there was a gap between the outcomes of those lab works and the required skills dealing with real world situations, noticed during the process of work defense, whenever students were required to apply to different situations reasoning that was supposed to have been the basis for interpreting data and making that particular report. These undesirable conditions exist to some extent in all the department engineering courses but seem to be particularly accentuated in courses such as thermodynamics, fluid mechanics and material resistance (Pierson *et al.*, 2002). An attempt was then made in order to try to invert such situation and, as the number of hours left little room to increase workloads, the option chosen was to redirect students hands-on lab work to real world situations, eventually complemented with lab work or lab instrumentation equipment when the works assigned would require so.

4. Work assignements

The students were given a preliminary description on the way lab and out-of-class activities would be developed. They were given a two week thought/consideration period, at the end of which they should either just indicate the particular three individual team composition or this composition and an area they would like to work with, materialized in a proposed work to be performed. In the end the proposed themes were:

Table 1 – Themes proposed by students' initiative

Work reference	Description	Tasks
Continente Viseu	Refrigeration plant	Determining the kind of system in use, present a general scheme, gathering data on components and refrigerant fluid, perform mass energy and entropy balances, evaluate the cycle efficiency
DOW Estarreja	MDI Polymeric Amine production	General description of the production process, environmental issues concerned, study of the boiler, perform mass, energy and entropy balances, evaluate the boiler efficiency
Cimpor Souselas	Cement rotary kiln	General description of the cement production, environmental issues concerned, types of rotary kilns, clinkering, perform mass, energy and entropy balances
Labesfal	Serum stove	Serum production description, analysis of the sterilization process, cooling tower operation, mass, energy and entropy balance
Vulcano BOSCH	Babystar plus water heater	Domestic water heaters, functioning modes, different kind of gaseous fuels, mass, energy and entropy balance of the 'babystar plus', efficiency

The remaining students, after being alphabetically ordered to constitute teams (allowing three subsequent days to accept any eventual recomposition by mutually agreed interchange), were assigned the following themes:

Table 2 – Themes assigned by professor

Work reference	Description	Tasks
SEFLOR I	Turbine and condenser	General description of steam turbines and condensers, Rankine cycles, data gathering, mass, energy and entropy balances, efficiency
SEFLOR II	Cooling tower	General operation principles, types of cooling towers, Rankine cycles, data gathering, mass and energy balances, gas mixtures, psychrometric chart
SEFLOR III	Boiler	General description of the process, types of boilers, data gathering, mass, energy and entropy balances, efficiency
SEFLOR IV	Water pumping system	Main line and supply system identification, characterization of the processes involved, Rankine cycles, mass, energy and entropy balances
Cerútil VISABEIRA I	Stove	General description of the process of utilitarian microwave stoneware production, environmental issues, type of stove used, drying process, data gathering, mass and energy balances
Cerútil VISABEIRA II	Oven	General description of the process of utilitarian microwave stoneware production, environmental issues, type of oven used, cooking process, data gathering, mass and energy balances
MADIBÉRIA	Cogeneration	MDF production description, general operation principles, types of cogeneration, cogeneration system in use, data gathering, mass and energy balances, efficiency
SIAF	Furnace and boiler	MDF production description, general operation principles, types of furnaces and boilers, cogeneration system in use, data gathering, mass and energy balances, efficiency
HDV hospital	Incinerating furnace	Incineration process description, general operation principles, environmental issues, data gathering, mass and energy balances, efficiency
HABIDECOR	Boiler	General production process description, types of boilers, types of fuels, system in use, data gathering, mass and energy balances, efficiency
Luís Santos & Monteiro (ex-PEXTRAFIL)	Cogeneration	Process of pulp production description, paper manufacturing, types of boilers, cogeneration system in use, data gathering, mass and energy balances, efficiency

All had the same time schedule, represented in Figure 1, emailed after the themes assignment:

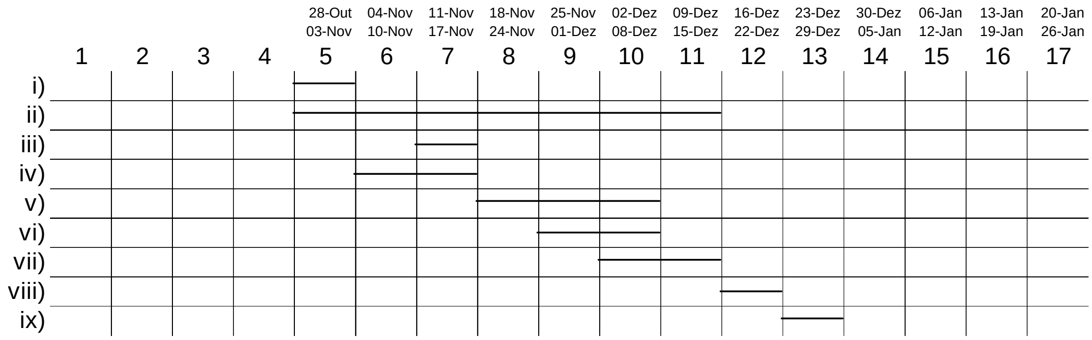


Figure 1. Work time schedule (legend in the following text).

The methodology to ensue was as follows:

i) Work description/Introduction
ii) Bibliographical and internet research
iii) Site/ plant/ enterprise visit
iv) Goal definition (I)
- intercalary report working up -
v) Data gathering:
(a) obtained directly in place
(b) to be experimentally obtained- *in loco* or in lab
vi) Goal definition (II)
vii) Computational work
- results presentation -
viii) Site/ plant/ enterprise visit to report results and, eventually, exchange points of view with the entities contacted
ix) Report delivery

The reports on progress were due until the end of each week, considered to be Saturday, in order to allow some time to revision and eventually sending corrections, either significant ones, either merely orientation (a paper sample was sent to serve as guidance for structure definition, maximum number of pages, styles, character sizes, and so on). Particular cases were taken into consideration, such as enterprise unavailability to receive team members or unsuitableness to develop the planned study, and the corresponding time schedules rescaled.

Students were allowed to make the first visit to the respective plant only after the professor gave them his green light, thus ensuring that the subject was already sufficiently internalized to ensure a productive displacement, as well as enforcing the need to avoid incipient immediate action and later reasoning, which is a practice unfortunately not too uncommon. All had to prepare a set of questions to ask to the enterprise representatives they were to meet. The amount of time to dedicate to such requirements as well as the research work needed was assessed through the analysis of intermediate reports, all starting with the introduction, a piece of work that was upgraded on a weekly basis in order to incorporate students state of knowledge over that particular subject.

5. Assessment rules

Non-compliance with the time schedule was the object of progressive penalties, within a maximum of three days delay. To help with the work implementation, assessment tables were sent by email and its contents explained in class. There were the paper work and the public presentation guidelines (Tables 1 and 2). One of the embedded purposes was to give an explicit sign of the relative importance of aesthetics issues, i.e., though being important to be able to deliver a nice and pleasant report (rated at a maximum of 15%) that should not obnubilate that the core of such report was its content and those issues directly related to it.

Table 3 – Paper work evaluation and quoting.

Written paper work	Mark (%)
1. General presentation	
Structure, links between sections, text formatting	15
Adequate use of Portuguese language (clearness, grammar, syntax)	15
2. Abstract and Introduction	
Abstract	5
Introduction definition and presentation	10
Work fitting	5

Table 3 – Paper work evaluation and quoting (cont.)

3. Contents	
Theoretical support	5
Data sufficiency	5
Analysis	5
Deepness	5
Reasoning	5
Computation	5
4. Results presentation	
Tables	2
Figures	3
5. Conclusions	
Discussion of results	5
Conclusions	5
Recommendations	
6. References and Nomenclature	5

5.1. Public presentation

Recognizing the importance of being able to communicate in public and addressing efficiently as one of the key issues to contemporary engineers (Black, 1993), as it traduces the capability of being able to deliver a clear message, with an adequate speech focused in a specific audience and recognizing the importance of convincing others of the good basis of proposals or statements, there is already a considerable period of time that these situations are created and a good performance is required (it is one of the most quoted positive aspects of the graduation organization referred by alumni in annual inquires) in the Mechanical Engineering and Industrial Management department. In this particular case, teams are ordered in an arbitrarily manner in successive groups of four teams, and requested to deliver their presentation within a 15 minutes period (a 5 minutes interval to change and load software, and eventually hardware, is expected). All their peers are thus present, the public presentation being performed in the faculty auditorium in one previously chosen day of the antepenultimate semester's week. Several faculty members are invited to appear during the presentation event that, due to the number of students, takes one whole day.

Table 4 – Public presentation evaluation and quoting.

Public presentation	Mark (%)
1. Technique	
Summary	4
Content	5
Importance	5
Detail	3
Logical structure	5
Visual aid quality	4
Comprehension	7
Knowledge	7
Answers and comments	4
2. Exhibition	
Spoken presentation	4
Goal definition	4
Audibility	8
Readability	8
Time management	8
Attitude	10
Audience sensibility	4
Presentation efficiency	10

5.2. Individual defense

The individual defense was made before a jury composed of three members. There were preparatory joint meetings between them to ensure consistency during the process of evaluation of the repots defense. All the assistant teachers had one students turn each and the questions were placed by the assistant teacher to the teams he had guided. A set of questions were prepared for each team-work, covering the main issues that were considered base knowledge and thermodynamics applied concepts to the specific case. Post meetings also occurred to ensure that the criteria of the marks assigned were homogeneous.

6. Results

In order to enhance and develop this initiative the best possible way, there was a continuously driven effort to sought criticism and advice from students, either individually, either through inquires passed during semester working time and suggestions were retained for next year course (and some of them even for next semester similar courses).

The results of applying evaluation items in described in Tables 3 and 4 are displayed in Figure 2.

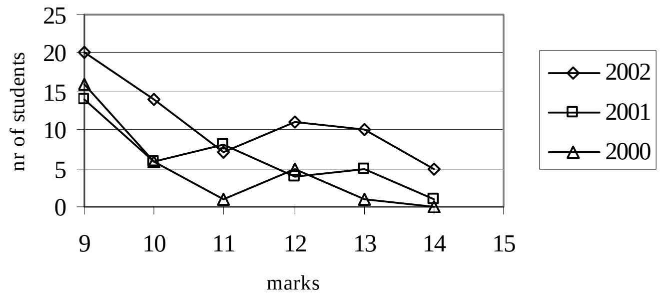
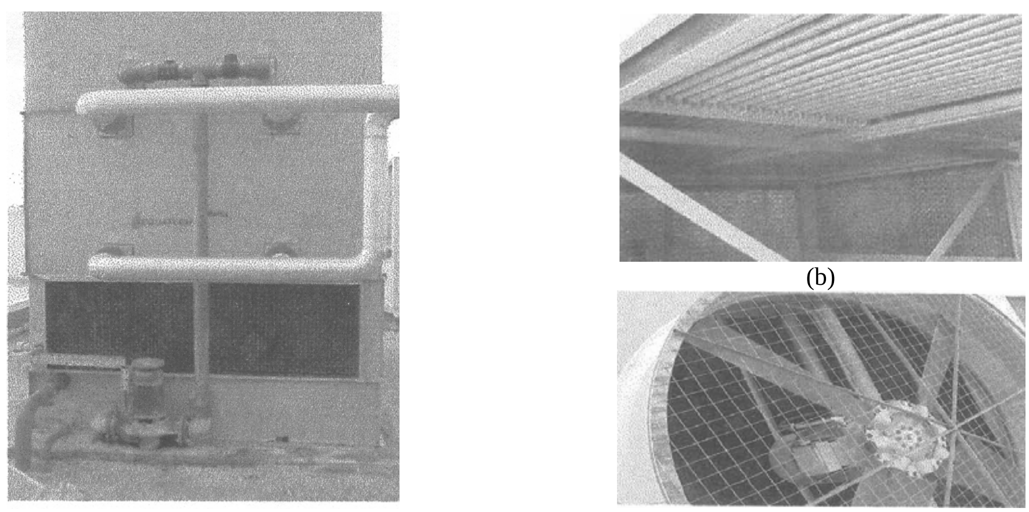


Figure 2. Marks distribution with the number of students.

Figure 2 represents the number of students that achieved marks below 9.5 in 20, 10 to 13 and 14 and above. It can be noticed that there was an increase both in the positive side of marks, and also on the negative one. If the first part can be interpreted as virtuous, positive result of the global approached adopted, the second is clearly a consequence of the individual defense introduction; though the mark composition was a weighed average of delivered written work (40%), public presentation (20%), individual defense (20%) and continuous evaluation during the semester (20%), the circumstance of having to submit to a jury was a decisive factor, though unfortunately only actuating near to the end of the process. It is expected that it will become a positive element, to add to honesty and transparence in evaluation, which are issues all teachers seek to enforce in collective work. Overall, comparing the last three editions of the Thermodynamics lecture, there is a sensible rise of marks above 12. Though the graphical presentation does not shows it, the number of higher marks is stable and do not exceed 15 in absolute value. It is not a situation that pleases us, but there is hope that, in the near future, some conjuntural measures will be taken nationwide that allow applying these same methodologies to higher level incoming students.



(a) (b) (c)

Figure 3. Cooling tower studied by Labesfal team: (a) pumping system, (b) coil and (c) fan (photos taken by students)

Nonetheless, this approach to real life situations has produced some results that deserve being outlined. Particularly those connected with the need to have initiative to cope with difficulties in data gathering, especially when the organization visited did not provide them, or provided data that turned out being unreliable. That was the case of the Labesfal team, the group having to study the serum stove chilled by means of a cooling tower (Fig. 3). At a certain point they had no way of obtaining data concerning the mass flow rate of replacement water, the internal temperatures and the outcoming air velocity. They asked for instruments for measuring them, took a data acquisition system with thermocouples, were 'remembered' on how to use Pitot tubes and hotwire anemometers, used buckets and stop-watches to measure water mass flow rate and even designed and proposed to the enterprise management a parallel device to install a thin plate orifice that would allow continuous measurements for monitoring purposes. That was the sort of engagement we were looking for.

Though it was necessary to anticipate for these team members the scheduled subjects concerning the gas mixtures and cooling by evaporation processes, they willingly found extra time to attend them, which were lectured on a informal way during meetings within teachers reception hours. One of the exercises of the final exam was about a cooling tower of a power plant. These team members were among those having the best marks in that question.

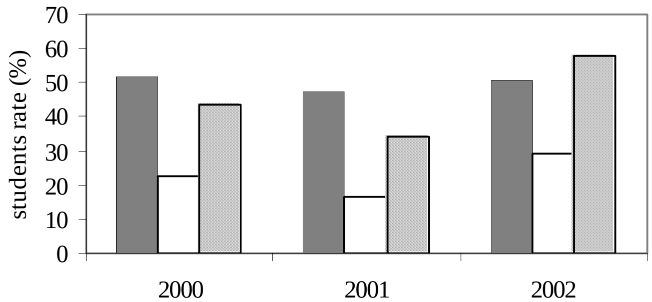


Figure 4. Students' attendance (filled), evaluation (blank) and success rates (cross off columns) for 2000, 2001 and 2002.

Other aspects to take into consideration are the rate of students attending the course, related to the registered number of students, that showed a slight increase, those that presented themselves to formal end of semester examinations and, mainly, the level of success from students able to pass the grade on a first attempt that clearly went from typical 30/40% to above 50%. Once again, this is not a bond that enables conclusive, final judgments, as the results reported must be kept within the proper time scale and await for future developments to strengthen this strategy.

7. Conclusions

Overall, this paper will be of any worth if it achieves, as it intends, to provide a somehow illuminating contrast to more traditional teaching methods/approaches to Thermodynamics, approaching the same issues through different windows and, perhaps, contribute to reflect upon and clarify the goals of teaching and the means of assessing and achieving the desired outcomes/results. Beyond the numerical results portrayed that must be kept within its limits, some aspects are highlighted, as positive outcomes of this approach, of which must be pointed out the increased level of attendance and the engagement from students throughout the semester.

8. Acknowledgement

The data needed to the preparation of this work as well as much of the teaching work involved is indebted to Professor Carlos Catorze of the Mechanical Engineering and Industrial Department, section of Energy and Fluids.

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