AC 2010-309: IMPLEMENTING BOLOGNA: AN ASSESSMENT OF A UNIFIED MODERN APPROACH TO TEACH THERMODYNAMICS AND HEAT TRANSFER

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Abstract

Ten years have passed since European higher education systems' Ministers formally agreed to sign the Bologna Declaration, thus establishing a strong commitment between EU governments to build a large educational area, improve transparency and, especially, compatibility between national systems. There is, however, an apparently minor aspect of this issue that tends to be overlooked: the change of focus from transmission of knowledge to acquiring skills, i.e., abandoning traditional scholarly pedagogical practices that relied on successfully completing syllabi and formal evaluation of students. The definition of academic and professional profiles should now be related to identifying and developing skills students have acquired. These are supposed to be the core items of the system's institutional and government assessment, which will eventually be performed under Organization for Economic Co-operation and Development/European Association for Quality Assurance in Higher Education (OCDE/ENQA) guidelines by a Higher Education Quality Assurance Agency (HEQAA).

This paper describes the implementation of a problem based learning approach in both thermodynamics and heat and mass transfer with the aim of achieving some of skills expected for competent engineering graduates. The measures that are supposed to allow for the construction of an adequate basic conceptual structure in applied situations are reported, at the same time that dealing with the need to formulate solutions to open-ended problems is supposed to fill the gap between theoretical and professional areas. Again, these are skills that shall be assessed under the HEQAA. Nevertheless, almost four years later, the internal assessment that has been carried out in these courses does not show significant improvements on the average level of graduates. This paper also tries to identify the main factors affecting this fact.

1. Introduction

Higher education, or Tertiary education, as the OECD[1,2] has recently introduced in its own Glossary of Statistical Terms, including Further education, is undoubtedly a major concern of governments. It has been recognized as one of the major drivers for economic competitiveness in a globalised world, which has been demonstrating how education is playing an increasingly important role. Europe is engaged in improving citizens' ability to deal with and being able to prosper in a world of ever increasing global competitiveness. The Bologna process is part of that strategy.

The OECD has defined two types of programs. Type A programs that represent heavily theory-based curricula designed to provide qualifications for entry to advanced research programs and professions with high skill requirements, such as medicine, dentistry or architecture. Type B programs are typically shorter than type A and focus on practical, technical or occupational skills for direct entry into the labor market, although some theoretical foundations may be covered in the respective programs. They have a minimum duration of two years full-time equivalent at the tertiary level. The maximum reduction that took place was between three and five years with engineering graduations appearing both in type A and B programs. This is also the Portuguese case.

ENQA, which was called to assess the system of the Portuguese Higher Education quality assurance, produced a report submitted before the end of 2006[3] pinpointing the systems' major weaknesses: limited independence, lack of sufficient operational efficiency and consistency, lack of consequences or follow-up on evaluations, lack of commitment from higher education institutions and lack of activity by the former Higher Education National Evaluating Commission (CNAVES).

Their recommendations were that a joint program accreditation with an academic audit at the institutional level, mixing different quality assurance methods, should be put in place, including both the element of control (accreditation) and the element of improvement (academic audit). Furthermore, an independent national agency for quality assurance should be established.

Going into more detail, the object of the evaluation is set out in legal documents, namely Decree Law 38/2007[4], and are: improving quality, developing a culture of quality and the provision of well-rounded public information on the performance of higher education institutions. Quality evaluation is compulsory and will take place within the framework of the European system of quality assurance in higher education. Considerable importance is given to the part played by the Dublin descriptors[5] on fulfilling minimum requirements.

The Bologna process has evolved since 1999[6] and is now in a phase of implementation which allows higher education institutions to foresee in the near future the actual consequences of not complying with its major trends. Dublin descriptors, regarding the qualifications that signify completion of the first cycle, state that the corresponding degree should be awarded to students who:

"*1. have demonstrated knowledge and understanding in a field of study that builds upon and supersedes their general secondary education, and is typically at a level that, whilst supported by advanced textbooks, includes some aspects that will be informed by knowledge of the forefront of their field of study;*

2. can apply their knowledge and understanding in a manner that indicates a professional approach to their work or vocation, and have competences typically demonstrated through devising and sustaining arguments and solving problems within their field of study;

3. have the ability to gather and interpret relevant data (usually within their field of study) to inform judgments that include reflection on relevant social, scientific or ethical issues;

4. can communicate information, ideas, problems and solutions to both specialist and nonspecialist audiences;

5. have developed those learning skills that are necessary for them to continue to undertake further study with a high degree of autonomy."

In 2005 the EU Commission introduced the EQF-LLL – European Qualifications Framework for Lifelong Learning, to provide a common reference to facilitate the recognition and the transferability of qualifications, based mainly on knowledge, skills and personal and professional competences[5]. A conversion between Dublin's and the EU's descriptors can be found in Annex 1 of the 2007 version of the document[5] and Tab. 3 below.

This paper describes the implementation of a problem based learning approach in both thermodynamics and heat and mass transfer, with the aim of meeting both professional competence and hard skills embodied in the Dublin descriptors, and tries to identify the main factors that make improvements difficult to implement.

2. Changing structures - the formal part of the process

The duration of the different study cycles was legally established by the government for the first cycle (the former bachelor graduation) corresponding to 180 European Credit Transfer System Units (ECTS), distributed over six semesters. This credit system takes into account all the student's work hours: classes, tutorials, preparation and lab experiments and study. The new degree has five subjects each semester, one less than the former degree. One very important change has to do with the fact that the number of hours per term has decreased substantially, from an average of 420 hours to the present 300; from the students' immediate point of view, each course was reduced from 6 weekly hours to an average of 4, *i.e.*, a one-third time reduction.

This new graduation is centered on the student's need to develop the necessary professional skills, namely in areas like production, industrial maintenance and industrial management. Curricular structure is strongly based on Mathematics and Physics[7].

3. The thermal sciences

The graduation has a set of classical courses which embody the area of the thermal sciences, such as thermodynamics, fluid mechanics, heat and mass transfer, thermal machines and combustion. Addressing the whole group with the same level of detail would present considerable difficulties. As thermodynamics and heat and mass transfer are two very close subjects, they will be the object of this analysis.

3.1. Some common aspects

There is common ground between the two courses and that common ground expresses the efforts that have been made to meet the expectations stated above: namely, those which concern the Dublin descriptors. But also some extra features that are the result of an acquired practice and that, though without representing major breakthroughs in changing the outcomes, are the expression of the faculty's belief that there is no process of learning more by studying less.

Some of the common features are:

i) On average, 3 out of 6 ECTS are used in classic oral exposition, using overhead projector (OHP) transparencies and power point slides, as well as the board to illustrate practical cases and exercises; approximately 2 ECTS are used with applied examples and questions and doubts related to that week's assignments. A minimum of 4 hours are dedicated to tutorials (extra classes), including a free Wednesday afternoon.

ii) Compulsory attendance of 75% of the classes; teams of 3 students are formed, voluntarily during the first two weeks, under the instructor's direction by the end of the third week.

iii) Self-grading: assignments, mostly exercises, are handed in by email every Friday evening; usually Saturday morning, again by email, the instructors provide complete handwritten and explanatory solutions[8].

Course -	TCM				
Team - 3	Bruno Fonseca (8410), Frederico Ferreira (6843), Paulo Cabral (5728)				
	Hélder Bernardo (8072)				
Assignment/Project -	kiln insulation				
Date - 070509					
	#1	#2	#3	#i	
1 - Technique					%
1.1 Summary		2			2
1.2 Introduction: content & importance		3			10
1.3 Detail & logical structure		2			4
1.4 Visual aids quality		2			4
1.5 Understanding	5	5	4		10
2 - Presentation					%
2.1 Objectives		1			2
2.2 Knowledge	5	2	4		15
2.3 Audibility	3	3	2		5
2.4 Visual aids clearness		5			10
2.5 Rigorous use of time		10			10
2.6 Posture	2	1	2		4
2.7 Sensitivity to the audience	1	0	2		4
2.8 Answers and comments	3	1	4		10
2.9 Effectiveness of presentation		4			10
	48	40	46	45	100
Comments -					
COMENTÁRIOS BIS!!!					
Não houve indicação da estimativa da energia armazenada na gravilha					
"Este ângulo foi determinado experimentalmente(…)"- como?!!					
Dicção Hélder					
Justificação do ângulo em função das dimensões interiores					

Figure 1. Sample grid of the evaluation of presentations by student teams.

iv) Handing in assignments: assignments are due and self-graded every week, within a week; they must include a short, comprehensive explanation of the difficulties faced, enabling instructors to follow up. When the class is approaching the term's ¾ mark, some of the exercises sent, normally 1 out of 3, have no accompanying solution, thus enabling the instructors to identify committed students. Instructors willingly try to help students to make their own way through the resolution, though never solving that particular exercise or problem themselves[9].

v) Problem-based learning: from the first day of class, a list of open-ended problems is handed out or a specific one is proposed with several concurrent approaches; teams will have three weeks to choose one of them. These tasks usually involve some lab work, not previously defined but which arises as a consequence of problem solving.

vi) In the last class of every second week, progress reports are presented to the class; evaluation grids are prepared for the assessment of presentations. An example is presented in Fig. 1[10].

There are items that are common to all the team members (1.1 to 1.4, 2.1, 2.3, 2.4 and 2.9), *i.e.*, that are typically a team's responsibility as a whole, and there are items that engage each member individually (knowledge, audibility, answers to questions from the audience, for instance).

3.2. Applied Thermodynamics

An overview of the contents that were obligatorily addressed when the graduation's cycle of studies was submitted to the Higher Education registration department is presented in Tab.

1. Applied Thermodynamics, though now with the “applied” qualification, keeps having an intrinsic strong conceptual and structural nature.

Table 1. Required data to register/accredit study cycles: applied thermodynamics curricular unit.

Course	Program	Competences	Professional work
Applied Thermodynamics	Introduction, Concepts, Units and Definitions Thermodynamic Properties First Law for Closed Systems First Law for Open Systems Second Law and Entropy Second Law for Closed Systems Second Law for Open Systems Power and Refrigeration Cycles Gas Mixtures and Air Conditioning	Calculating energy balances and identifying changes that take place in closed systems (tanks, compartments, systems) Idem in control volumes (valves, compressors, turbines, pipes) Operating steam power, refrigeration and air-conditioning cycles Thermal designing plants and selecting equipment Using measurement and calibrating devices	Energy production Refrigeration Thermal behavior

3.3. Heat and Mass Transfer

Although heat and mass transfer is in directly connected to the preceding contents of the thermodynamics course, it is more tangible or “physical” in nature. Therefore, it can be more directly driven by practical issues. Again, an overview of the contents submitted to the higher education registration department is presented in Tab. 2.

Table 2. Required data to register/accredit study cycles: heat and mass transfer curricular unit.

Course	Program	Competences	Professional work
Heat and Mass Transfer	Introduction, Basics of Heat Transfer Heat Conduction Equation Steady Heat Conduction Transient Heat Conduction Fundamentals of Convection Forced Convection Natural Convection Fundamentals of Thermal Radiation Radiation Heat Transfer Mass Transfer	Identifying and analyzing transfer phenomena Insulation dimensioning Applying thermal behavior regulations to specific cases Using measurement and calibrating devices	Heat Transfer and Combustion Thermal behavior of buildings

4. Problem-based learning

4.1 (semi) Ill-posed problems

A sheet of paper containing the proposed subjects for that term’s activity or activities is distributed among students attending the first class of that term. A general discussion ensues under the instructor’s supervision. That draws the boundaries for the activities, namely those concerning budget issues.

Figure 2. Sample PBLs on "Why is Thermodynamics Applied?"

1. A spa's hot water system needs to be replaced. The current system consists of two mural boilers (one for the male spa, the other for the female) and the goal is to replace it with a solar energy system. 50 baths per hour are taken in each 1 hour period class day. One bath takes an average of 5 minutes, with the particularity of the baths being taken in the last 10 minutes. How shall the system be designed (capacity of the reservoir/tank and area of the thermal solar panels, and so on)?
2. A wine cooperative needs to follow the new trend in wineries and make the fermented mash at a low temperature of 26º C. As this is an activity that takes place at the end of the summer, beginning of autumn, it is not unreasonable to expect temperatures around 35º C in the months of September and October. If the mash is inside a cylindrical container with a diameter of 1.8 m and a height of 4 m, which features should a machine have that allows withdrawing some 200 W/m3 of energy released during this process, while maintaining the desired temperature of fermentation?
(...)
8. Your future employer tells you that you need to design a system to convert enrgy from biomass (which is the industry term used to describe the fuel obtained directly from trees and plants). This system should be able to provide sufficient thermal and electric energy for the inhabitants of a single-family house. What do you do? Which engineering proposals can be made? How much fuel will be needed? Please note and explain all the steps you take, indicate clearly all the assumptions made and consider 15,000 kJ/ kg for the HHV of the biomass.

Figure 2 has some examples of the problems laid out in the academic year of 2008 in applied thermodynamics. Similar problems are proposed in heat and mass transfer or, as in the 2009 academic year, a single problem, with multiple concurrent approaches may be provided. In both cases, teams are mandatory and a leader/coordinator of each team is nominated by the students or appointed by the instructor around the third week of classes. The instructor has the possibility of removing the team's leader if he or she fails to attend more than two consecutive meetings, usually held on Thursday or Friday afternoons. Those are approximate one-hour meetings, which are held to discuss issues arising from the development of the activities and to monitor and track progress against previously defined milestones. They are irreplaceable in order to maintain (and sometimes adjust) timelines. Another decisive aspect of these weekly meetings are that they provide a common ground for knowledge and transfer important information and suggestions from all coordinators, thus increasing the likelihood of achieving the established goals. Two afternoons were available for all of the teams to meet the instructor in the lab facilities.

In 2006/2007 a problem was posed concerning a MacDonald's fries: "Do you think you could improve McDonald's fries and produce a textbook to successfully fry the best French fries?" The discussion on what was a good French fry began, and after a while the good fry was defined as a regular sized piece of potato that is simultaneously baked on the inside and crispy on the outside. Students were assigned to search for more detailed information on that subject and to give an oral presentation during the next class. Meanwhile, the problem proposed was, in order to bake a piece of potato with the same dimensions as the French fry, to investigate the possible use of the Lumped System Analysis. Next, some convection fundamentals were taught and students used them to look into the subject and eventually calculate, by means of a semi-empirical correlation, an approximate value of a natural convection coefficient. This subject was worked on until the end of classes. It was the anchor of the remaining topics; it was used to address bi-dimensional conduction, to use the Heisler and Gröβer charts[11], to deal with semi-infinite solids (and understand the attractiveness of that usage), to calculate different convection heat transfer coefficients to cope with the fact that a rectangular prism, such as a fry, has horizontal and vertical planes; to simulate fin behavior, with the same dimensions, exposed to a high temperature fluid.

A request from the Electrical and Electronics Department to assist on one of their student teams on the best way to ensure a proper sequence of temperatures inside an oven where a printed circuit was to be thermally treated/cured was the starting point for the 2007/08 PBLs. Finally, in the 2009 academic year, an ongoing EU funded project on biomass for energy that needed the assessment of a region's specific shrub drying ratios occurring using solar dryers led to the solar kiln PBL**.**

4.2 Experiments

Applied thermodynamics has been using good lab equipment available and experimental activities involving the use of refrigeration equipment, as well as HVAC, are common. Energy conversion using a small vapor power cycle plant is one of the most popular experiments. Theoretical results are compared to experimental data gathered by a data acquisition system. Teams are only allowed to carry out experiments after passing an oral examination[12].

The level of integration achieved with these experiments is clearly lower than the one described below for heat and mass transfer. In this case it was possible that, when dealing with the French fry issues, and after realizing that vegetable oil was not an electrical conductor (through an internet search where a German student proved the point by totally immersing a motherboard into an aquarium filled with vegetable oil), a specific, deliberate experiment was designed. Analysis of the results showed that a serious effort was made to link observations with theory. For instance, a significant temperature decrease was registered at the surface , compared to the data being recorded by the inner thermocouple in Fig. 2. This led to the recognition of the latent energy used for phase change as water inside the potato was evaporating at the surface and merging into hot oil. The natural convection hot horizontal surfaces hexagonal pattern, which description was always a bit "fluid", was identified during the frying experiments (Fig. 2). The transient heating process of the electric frying pan was also used to determine electric consumption and the amount of energy needed to fry 500 g of initially frozen potatoes.

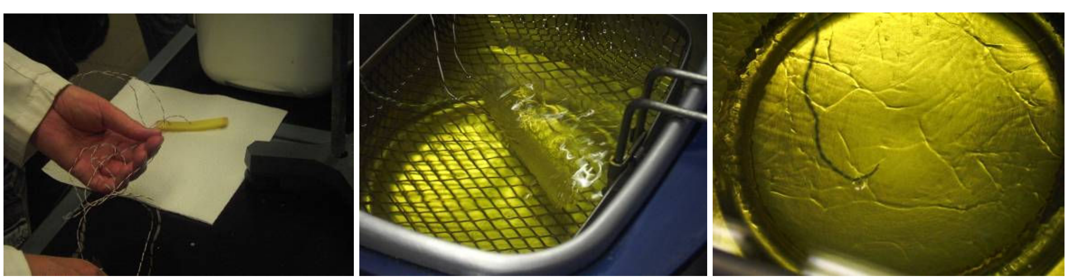

Figure 2. Wiring and frying the French fry (upper surface of a hot plate, natural convection).

In the end, the data was compared with the theoretical results, in order to assess the amount of time needed to steam and fry the potatoes. And although this was an atypical situation, the order of magnitude involved was quite satisfactory.

Figure 3. Wiring and preventing the thermocouple from direct exposure to radiation; IR emission.

The thermal treatment was intended to make the resin over the printed circuit experience a temperature value evolution pattern that would cause a pre-heat, soak, reflow and cooling sequence, all within very tight time intervals.

Different heating electrical resistances were tested inside a small lab furnace and the internal air temperature evolution data acquired to assess if the required conditions were being met.

Figure 4. Solar kiln designed to dry 60 kg of local shrub species.

The solar kiln project that led to designing, building and testing the device shown in Fig. 4, can be more thoroughly appreciated by visiting the site/blog created to show all the phases of the process, as well as the team's explanations on the way they tackled, interpreted and solved some of the difficulties encountered[13].

4.3 Follow-up

For all the projects in progress, a file containing the corresponding presentation report is emailed to the instructor by the team's leader every other week. The document is evaluated on substantial issues but also on the formal observance of reports and presentations rules, namely those concerning the structure "Title, Summary, Table of Contents, Introduction, Analysis, Procedure and Results, Discussion of results, Conclusions and References".

Follow-up of self-graded assignments takes place every two weeks as well as lab work and guided visits reports, if applicable. A file (like the one presented in Fig. 5) is emailed to all students so that they can check the accuracy of the data displayed, namely regarding the exact number of assignments handed it.

Students called it “the debtors’ list” and, quite surprisingly, is a major factor in keeping healthy pressure on handing assignments in on time (also because lateness is only tolerated one week and those assignments marked down 50% and in red).

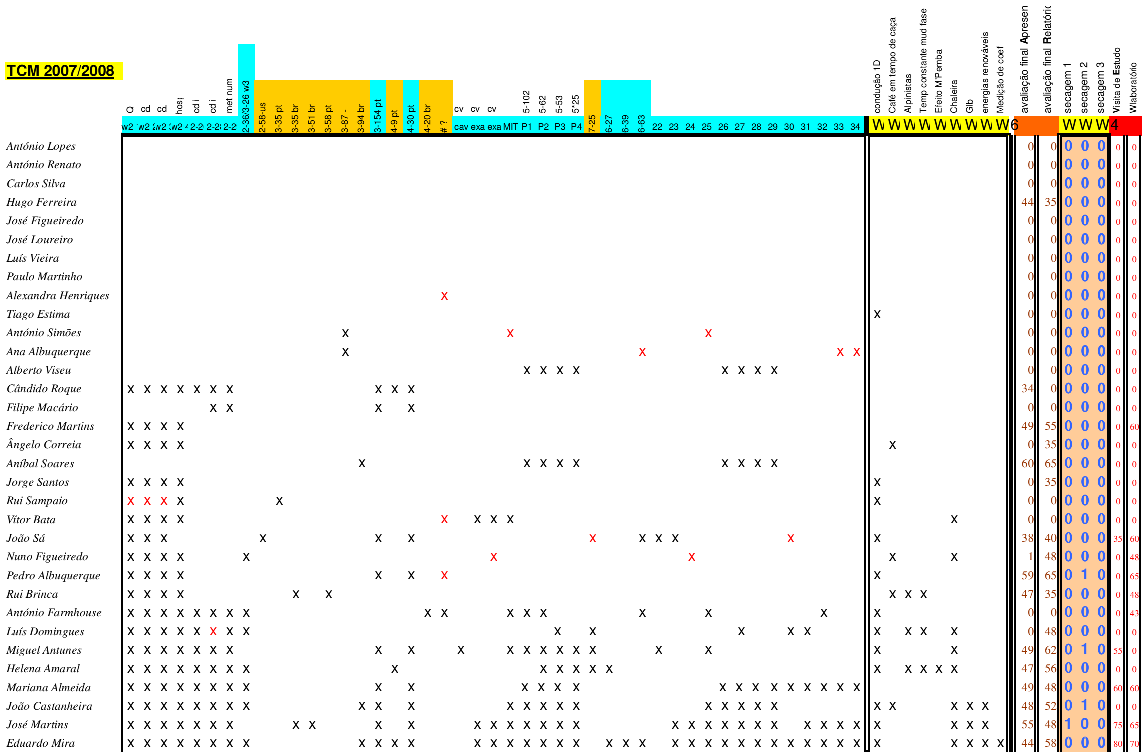

Figure 5. Truncated sample of a list of continuous assessment for one shift.

4.4 Formal evaluation

Figure 6 shows the common structure used in the formal evaluation in this area:

Questions 1 to 4 are the kind of questions that can be found in Fundamentals of Engineering (FE) exams and are multiple-choice questions which address a maximum of two consecutive steps in the solving process. They are intended to evaluate acquired “knowledge”, a learning target that can be considered to consist of acquiring facts, concepts and theories. In preparing these multiple-choice questions, instructors choose which subjects they want to test.

In addition, as they are numerically based quizzes, they also address and reinforce the need for accuracy in results, which is fundamental to reincorporate in the learning process too often exclusively focused on reasoning. This part of the evaluation also aims at rewarding knowledge, comprehension and application obtained by means of regular study in class. The overall weight of the test is 40%.

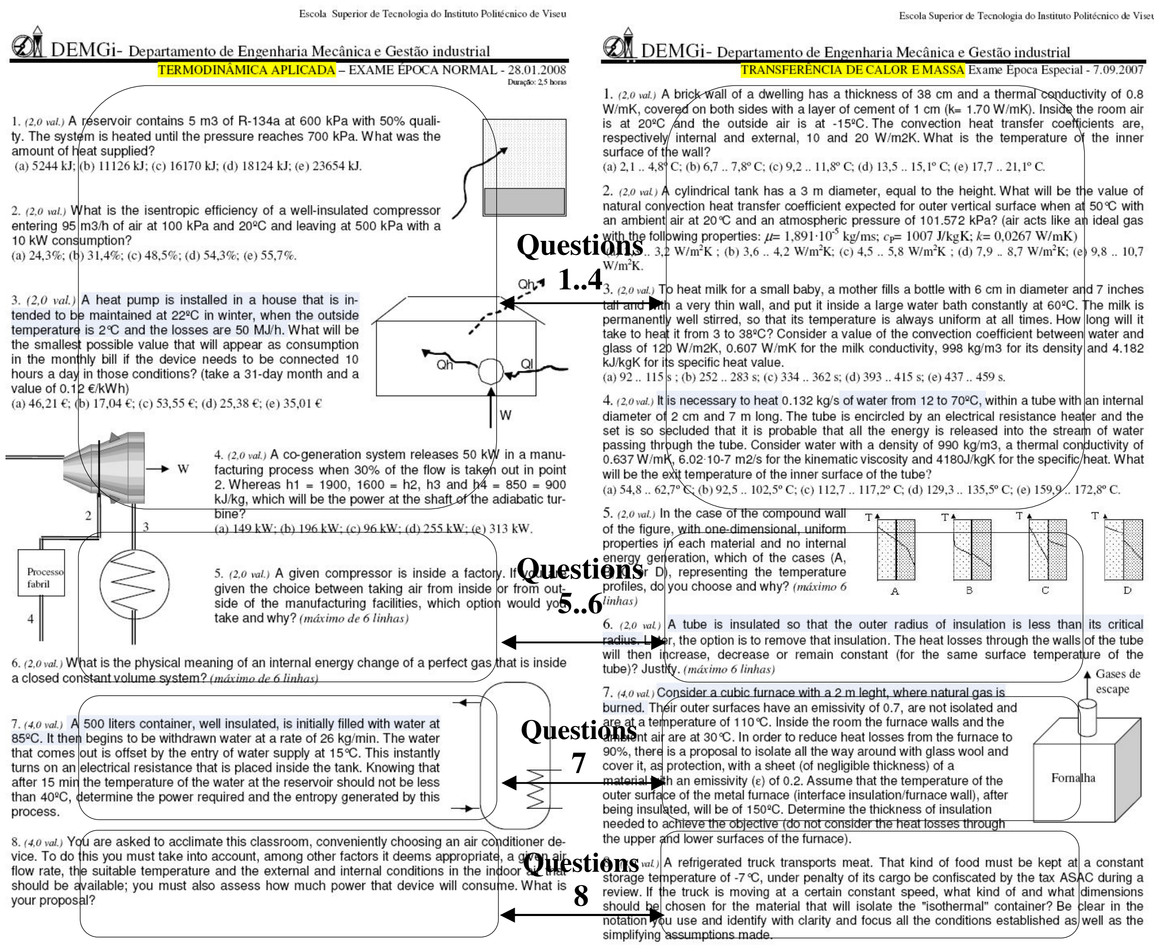

Figure 6**.** Examples of test's structure in applied thermodynamics and heat & mass transfer.

Questions 5 and 6 are usually conceptual questions. They stress the importance given to understanding the physics of processes: "Should you face the choice from where a compressor must aspire air from, the plant's internal or external facilities, which one would you choose and why?", "Why do glasses fog up when you enter or leave a café in winter?" and "If pipe insulation, whose thickness is such that the insulation radius is smaller that than the critical radius, is removed, will the rate of heat transfer increase?"). This group of questions also tries to evaluate the 'reasoning' learning target, questioning the conceptual understanding of common domestic and professional phenomena. These questions] can be found in many textbooks (Çengel[14] and Çengel and Boles[15] are the authors who deserve the greatest credit). This section accounts for four points, *i.e.*, 20% of the overall mark.

Question 7 is the traditional "problem", in the sense that this kind of question will be the object of a "constructive" correction, with a good deal of credit given to developing reasoning and not only the final result. Question 7 is worth 20% of the final mark and can address both the second and third of the Dublin descriptors.

Question 8 is intended to provide an insight into the results obtained in the assessment, mainly, the third and the fifth descriptor. On most occasions, these were questions that closely replicated, though not formally, the issues that were dealt with in PBLs. For instance, when the French fry case was developed, question 8 in exams that year addressed situations where both the required knowledge and the geometry were close to transient heat transfer in large plane walls, using data previously acquired by a data system; with the solar kiln, questions were related to decisions on and logical concatenation of data and steps that would be needed to pre-design drying equipment.

5. Results and discussion

The results of three consecutive years in applying the described set of pedagogical operations are presented in Tab. 3. They represent assumed formal point of view, *i.e.*, they are the test results for the two courses for the academic years from 2006/07 to 2008/09.

Table 3. Discrete results for applied thermodynamics (ATD) and heat and mass transfer (HMT).

Test question #	Descriptors		2006/2007 (%)		2007/2008 (%)		2008/2009 (%)	
	Dublin	EU	ATD	HMT	ATD	HMT	ATD	HMT
			99[a]	106[b]	119[a]	91[b]	120[a]	82[b]
1..4	1 2	1, 2, 3 3, 4	27	35	32	28	17	41
5, 6	3	10, 11, 12	32	23	7	30	18	35
7	2, 3	3, 4, 10, 11, 12	20	4	10	17	22	38
8	3, 5	7, 10, 11, 12	7	21	19	12	13	15
Success rate$_{tests}$ (%)			17	18	20	12	11	32
Success rate$_{final}$ (%)			17	16	19	12	11	36

([a]): number of students evaluated in applied thermodynamics
([b]): number of students evaluated in heat and mass transfer

The values presented are the average of three assessment sessions for each academic year: one designated "normal", a second "appeal" and one extra. These sessions are laid out in the polytechnic's internal pedagogical regulation and are a common situation in all Portuguese higher education institutions, but they do not appear to be a good practice: students who study regularly are not rewarded and successful results do not increase due to this fact alone.

It is worth mentioning that the decrease in the number of students evaluated in heat and mass transfer is the result, on the one hand, of the change that occurred in the curriculum of the Mechanical Engineering graduation, from the second to the third year. On the other hand, it is not available in the Industrial Management degree. This is not the case with applied thermodynamics, where it is compulsory in the second year of both degrees. To give deeper insight into overall results, "Success rate final" represents the overall success rate as it includes both test results and continuous assessment resulting from homework assignments, attendance "quality" (the difference between just sitting there and effective participation), PBLs, presentations, laboratory work and reports from class trips. Both components require a minimum of 9.5 out of 20.

That said, the first unavoidable conclusion is that the overall results are far from being good. The only reason why they are not considered unacceptable is related to not having a regime of a limited number of possible enrolments effectively in place. Actually, there is one but, for political reasons, it is still under prorogation; it is supposed to come into effect and to produce changes by the end of 2009. Until then, many of the students enrolled will either keep missing classes altogether or attending but not working sufficiently. The fact is that there is a strong individual correlation between students who present good average results in Fig. 5 and final success in both courses. This is a clear indication that continuous work and commitment are key factors to success and need to be enforced and “internalized” by the student culture and the sooner the better.

As for evaluating the effects of Bologna process, by this perhaps controversial method, the results seem far from being. Those skills and competences that question 8 was particularly intended to test for are showing a strong between expectations and the outcomes. Question 8 clearly addresses the EU’s tenth descriptor, for the second cycle of studies (though at the seventh reference level): “Solve problems by integrating complex knowledge sources that are sometimes incomplete and in new and unfamiliar contexts”[5]. And that does not seem to be happening. Some say that one of the problem in engineering today is the tendency to promote students based on their math and physics skills whilst showing unconcealed contempt for recognizing or encouraging the one skill that engineering is all about: making things[16]. In the case of these two courses, attempts were made to reach that goal but the results are not forthcoming.

6. Conclusions

The results of the formal part of the evaluation are not encouraging, especially if short term results are to be assessed. Nonetheless, looking ahead there seems to be no other way than to continue efforts to support the ambitious desideratum that mixes knowledge, skills and autonomy, responsibility, professional and vocational competence. One of the problems that must be addressed is the fact that students misunderstood the changes brought on by Bologna as a way of easing their academic careers. The reduction of the number of traditional classes, contact hours between the instructor and the students, turned that initial sensation into something “real” from most of the students’ (unconscious) point of view.

One of the main issues regarding the reshaping of higher education in Europe is the assessment of the outcomes in terms of improved quality, that can be defined as “the process of establishing stakeholder confidence that provision (input, process and outcomes) fulfils expectations or measures up to threshold minimum requirements”[17]. This will probably be the stage at which the verdict will have to be clear-cut: either lowering standards to meet efficiency ratios or keeping up with a rigorous approach to guarantee improved quality of knowledge, skills, personal and professional competence.

But, as an old professor used to say: “*Easy schooling, difficult life.*” Does it still hold true?

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