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BUILDING BRIDGES BETWEEN INTRODUCTORY PHYSICS COURSES AND APPLIED THERMODYNAMICS

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Abstract. *The present paper describes introductory physics curriculum revisions that have taken place in the Mechanical Engineering and Industrial Management Department during the last two years, particularly those undertaken in order to ensure a better understanding of basic thermodynamics concepts. Being traditionally focused towards Newtonian mechanics, introductory mechanical engineering physic courses tend to narrow first impressions about the roots of applied subjects to come. This results in loosing an important amount of first quality curiosity as well as induces some detachment from freshmen that may not be completely committed to this engineering course, thus reducing our ability to increase retention at a most crucial early stage of the course. Although nowadays success in engineering is becoming increasingly dependent on proficiency in skills that aren't limited to technical ability, many students select engineering not because of the solid education it provides or even as a result of a strong interest in the technical aspects of common devices but mostly because they have expectations of potential interesting income.*
There have been important changes both in the role engineers play and also in the social and educational background of the student's body entering engineering faculties. We now receive individuals from all sections of society, who often have little knowledge of the way mechanical devices work as well as a lack of hands-on experience. This is particularly noticeable when heat-pressure-work concepts are introduced. Traditionally located in the second year of the curriculum, thermodynamics requires pre-teaching some basic concepts with the purpose of providing the basis for applied energy conversion through heat machines.
The goal is, therefore, to ensure an appropriate coverage of a wider number of subjects, using a more diversified and stimulating program, which preserves the strong foundation in engineering sciences that characterized the previous syllabus.

***Keywords**. Engineering education, Physics, Thermodynamics.*

1. Introduction

Portugal has been trying to keep the pace with the industrial western economy increasing the rate at which qualified human resources are feeding the productive activities. The fact that during half century its industry was conditioned and kept at a low level of activity made the necessary recover more difficult. Particularly at higher education level, only in the eighties, after a marked political shift, was taken one of the decisions that would enforce the required transformations: the creation of a polytechnic system. Though the enlargement of the recruitment pool that followed has showed the main hindrance to be a shortage of teachers who could adequately prepare high school livers for further studies, almost twenty years later the focus is now placed on the capacity required to turn them in competent professional individuals. The doubts concerning the direction educational systems in the European Union must follow, particularly at k12 level, resulting in a widespread uncertainty, makes an even more important issue of what is considered an inefficient acquisition level of general knowledge in those that intend, and actually did, enter higher education. On the other hand, there is a significant trend towards the reduction of educational budgets, which makes increased efficiency and versatility imperative, and forces institutions to improve their performances (Meyer-Dohm, 1990; Simões *et al.*, 1999).

2. The mechanical engineering course

The Mechanical Engineering graduation, which last November commemorated its 10th anniversary, has been striving to develop a curriculum that allows the acquisition of the knowledge and skills necessary for a competent professional life. Besides boasting several staff members who also work in industry (and who therefore can provide continual feedback), a 3-month training course is obligatory at the end of the course to obtain the diploma, with assessment from both company and school determining the final grade award. Furthermore, areas such as Materials Resistance, Thermodynamics, Fluid Mechanics and Electricity as structurally underpinning the course, are considered essential in training the kind of engineers we are seeking to produce. Such areas facilitate the transition from technical to technological areas of knowledge.

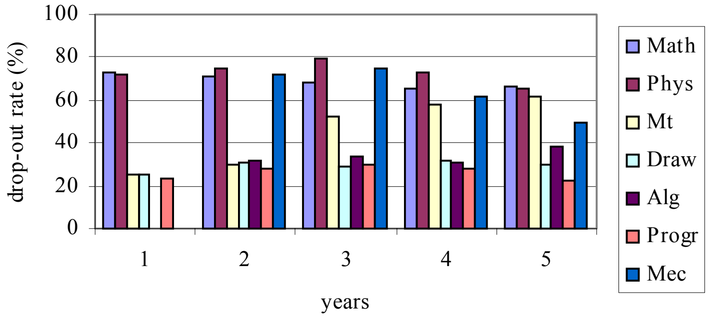

Figure 1. Drop-out rates, first year (Math- Mathematics, Phys- Physics, Mt- Metallurgy, Draw- Technical Drawing, Alg- Algebra, Progr- Programming. Mec- Mechanics; 1- 1996, 2- 1997, 3- 1998, 4- 1999, 5- 2000).

The assessment of the residual deep knowledge in those fields already had made clear that these subjects had become, along with Physics and Mechanics, the factors that more sensibly influenced student dropout rates. And that, most of all, they were negatively influencing the rate of retention, as the major part of the dropouts were reported to occur at the end of the first year.

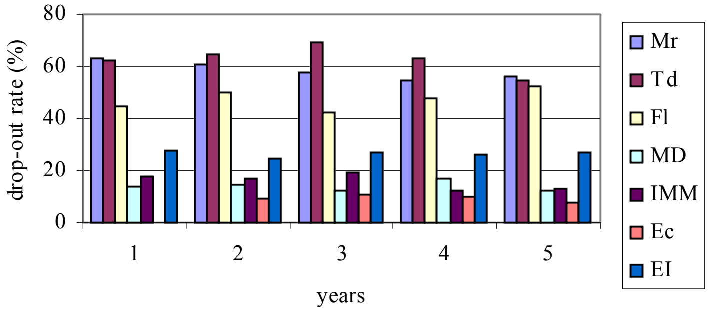

Figure 2. Drop-out rates, second year (Mr- Materials resistance, Td- Thermodynamics, Fl- Fluid Mechanics, MD- Machine design, IMM- Industrial maintenance management, Ec- Economy, EI- Electronics and instrumentation; 1- 1996, 2- 1997, 3- 1998, 4- 1999, 5- 2000).

The school has conducted several surveys since 1995, under the ambit of both internal and external assessment programs, guided by Adispor- the Portuguese board for Polytechnic evaluation. In all of the surveys the results of the Mechanical Engineering and Industrial Management Department had a very high rating in areas such as employer satisfaction. Similar feedback was received from mentors of the students while on work experiences.

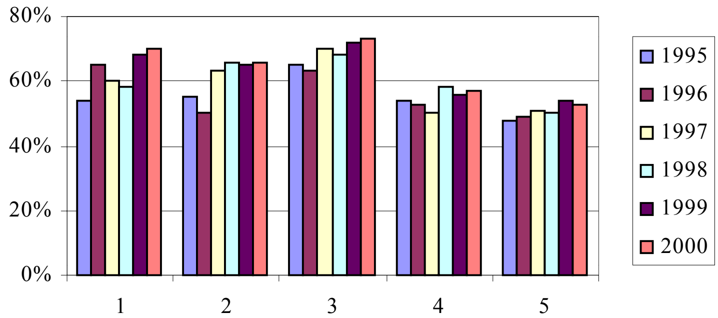

Figure 3. Satisfaction index (good and very good) surveys to employers (1- technical knowledge adequacy; 2- integration ability; 3- responsibility; 4- multi-focus capacity; 5-dialogue capacity)

Some initiatives were carried out such as analysing the official curricula of the state high school system and contacting regional high school teachers to identify the actual content covered; assessing the freshmen's initial knowledge and skills in order to prepare revision tutorial classes; decreasing the number of students per class; revising lab classes; and implementing extra tuition classes (Vinhas and Paiva, 2000).

Those measures were not sufficient to solve the main dropout issue. Students kept failing their physics and physics based modules, maintaining the trend to abandon the course after the first year (an average of almost 40 % during the last three years), while those that did graduate continued to take too long to complete their studies.

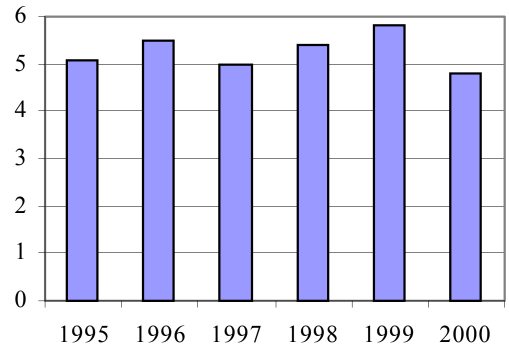

Figure 4. Years of study per pass degree of 3 nominal years.

It was decided to conduct a survey to find out what expectations former freshmen had when choosing mechanical engineering and industrial management, and what were the main threats they felt when entering the course. Regarding the first issue, the answers indicated a strong concern with employment as well as potential high income. As to the second one, the main anxiety detected was "not being able to cope with Mathematics and Physics" and "not being able to succeed in a course that had a reputation of being solid but very difficult". This last issue was somehow consistent with the grades students presented at arrival. The consistently low average national grades in Maths and Physics made us aware that the situation was almost the same all over the country, forcing the department to make serious efforts to adapt educational practices to counter the difficulties experimented by the incoming students (Postic, 1995).

3. Broad initiatives

A series of measures were planned, namely abolishing classical separation between theoretical and tutorial classes (schedules indicating the name of the subject but no longer the nature of the class) and enforcing a regime of attendance recording. The course curriculum was rearranged so that subjects formerly considered to belong to 'structural' areas were clearly identified as engineering issues. These were then rescheduled in order to provide engineering practice. The results can be observed in Fig. (5).

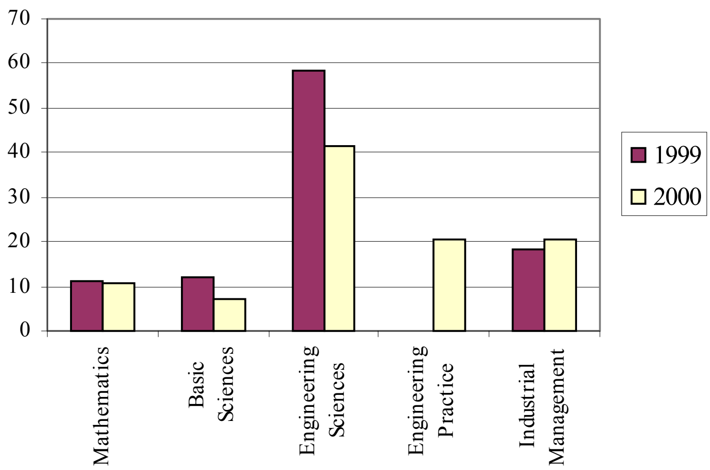

Figure 5. Curricula rearrangement number of weekly hours in the course.

Lab work was structured within a mainframe distribution throughout the semesters consisting of a sequence of 2+6+6 weeks. Whenever possible, the first two week's experiments should be carried out by the teachers, followed by lab work installed and performed by students; synthesis experiments could be offered as options to be chosen or even created by students, and could be accomplished in the last month of the semester. All this was accompanied with precise indications of delivery dates for each kind of work and the maximum number of pages, as well as worksheets indicating, and informing, the kind of evaluation marks to apply.

4. Physics

One question involved the reason why Newtonian mechanics was so difficult to grasp, which might be related to the abstract and non-intuitive nature of mechanical concepts and also to the complex formality with which it is normally presented. The first step was to interact with the freshmen's acquired view of the world (Neto, 1998). Active behaviour was encouraged in order to stimulate 'active' perplexity regarding phenomena freshmen were convinced that they had mastered. Simple experiments were prepared as a way of understanding how freshmen explain some apparently obvious situations and providing the possibility of recognizing and detecting the acquired schemata in the comprehension of physics.

One example of this kind of strategy is the double transparent glass spheres, connected by a tube, containing coloured water. Grasping the lower sphere with a (warm) hand makes the air expand, causing the water to (appear) boil, thus inducing the erroneous idea that the liquid is changing of phase. Using a Torriceli barometer in class can also provide a solid comprehension of the existence and understanding of atmospheric pressure and, putting to work vacuum manometers help to clarify pressure nomenclature.

Traditionally the Physics studies of freshmen are mainly concerned with Mechanics. Unlike the other Physics subjects, Mechanics may be a subject which we become familiar with from the time of our birth onwards, as we construct a set of spontaneous and intuitive theories, which are for the most part completely divorced from scientific reality. So, in a Mechanics course, the student faces a conflict between two different ways of observing the world: one created from intuition and common sense, structured in a natural logical way, and the other one abstract, based on a formal "unnatural" logic (Neto, 1998).

A common situation that can be pointed out is related with the comprehension of the forces involved in the interaction of bodies. The concept of force, as an associated entity with an interaction, is more in evidence in Newton's third law, and the students only begin to understand this concept when they are able to apply it correctly, drawing the force diagrams of interacting bodies properly. A great number of students correctly represent the external forces, namely the friction force when it is caused by its interaction with the ground.

Some difficulties arise when it is necessary to represent the friction forces developed between two bodies and analyse the different possibilities of dynamic behaviour of the second body, relating them to the motion of the first body. In order to understand the effect of the forces acting on the system, some scale models were created to observe bodies' dynamics in different situations. The drawing and analysis of the corresponding force diagrams leads to the comprehension of the effective behaviour of the system, contributing to the construction of a correct vision of mechanical phenomena. From this we can move on to molecular randomness, introducing pressure from microscopical scale, as well as temperature as molecular agitation, turning friction into heat.

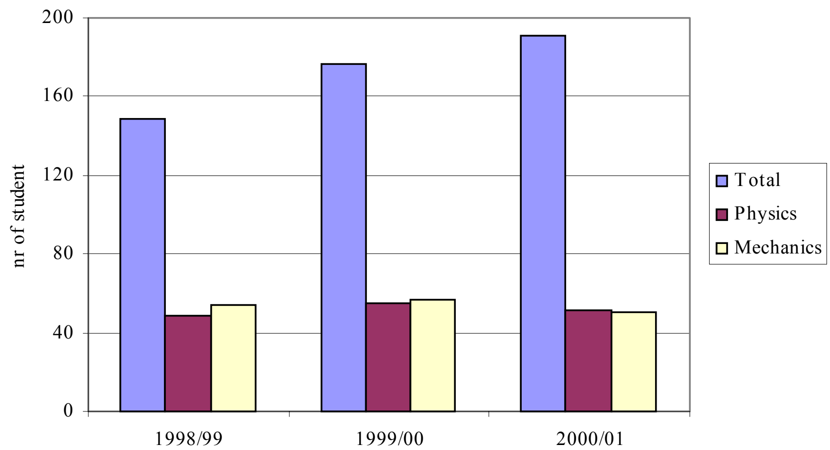

Figure 6. Total number of student versus academic year, compared with dropout number per subject (Physics and Mechanics).

As a result of all these barriers, there is a considerable abandon during first year, mainly due to the absence of success in Physics and Mechanics, which can be observed in Fig. (6) and in Tab. (1).

One of the measures adopted in order to seek improving retention was to allow an introductory and conceptual formation in basic domains of Mechanical Engineering.

This gradual change started with the introduction of a new Physics curricula, designed in order to include introductory approaches to Thermodynamics, Fluid Dynamics and Wave Motion, therefore conducting to a more diversified syllabus with new subjects, which intends boosting students' interest and creating new opportunities of broadening their relation with real world.

Table 1. A- Total dropout number of student; B- dropout number of student that succeeded in Physics and Mechanics.

		A	B
1998 – 1999	Physics	49	1
	Mechanics	54	3
1999 – 2000	Physics	55	1
	Mechanics	57	1
2000 – 2001	Physics	51	2
	Mechanics	50	0

Improvements on better classes delivery would also become easier when progresses were made trying to achieve a better understanding on how students think and make their particular approaches to the subjects, rather than just delivering scientifically adequate and present contents.

5. Introductory Thermodynamics in Physics

Some of the difficulties experienced by students arriving at 2nd year Thermodynamics, via the old curriculum, were related with some basic concepts, namely those that provide the basis for understanding one of the core knowledge goals, the applied energy conversion through heat machines. Therefore, attempting to reduce the gap between the existing knowledge, acquired with the successful attendance of first year physics, some emphasis was placed dealing with some of the particular issues involved. In the case of introductory thermodynamics, special care is given to the common use of 'conservation of energy' term, as usually it is a way of expressing concern with energy waste in everyday language or associated with visible movement, living beings or technical appliances (Watts, 1983; Bliss, 1 985; Trumper, 1993), rather than scientifically meaning that the energy of the universe is constant. The great majority of students lack personal experience of work production through heat transfer. Most of the attempts to direct attention exclusively to car engines fall short. Good results though have been obtained with educational visits to small and medium size power plants, especially those recycling wood waste. Similar results can be achieved visiting small-scale industrial refrigeration plants, such as those in large supermarkets and fruit depots. Hospitals and recreation centres (incorporating ice facilities) also present good opportunities to interact.

5.1. Language and explanations- some issues

The distinction between work and heat is also of major importance to be treated on a basis of mutual exclusiveness (at least until entropy is introduced)- what cannot be recognised as energy transfer due to a temperature difference, is work-, as well as the emphasis on electric work versus heat transfer. Heat is normally referred to as a type of transfer energy between two systems, thus colliding with the 'quasi-material' conception (Duit, 1987) of 'being stored' in a system/container/vessel. Though some authors wonder if an understanding closer to the 18th century caloric model might be a realistic teaching aim, Warren (1986) states that "energy is not a tangible object, it is a mathematical abstraction which can only be 'experience' by disciplined thinking". Recognising that in teaching science it is often impossible to immediately and understandably tell the whole truth (Kaper and Goedhart, 2002), we prefer experiencing a 3rd way, by means of an attempt to define and use an adequate framework of appropriate reasoning, that, in order to pursue a higher quality comprehension, should encompass the following issues (Viennot, 1996):

. careful identification of the systems concerned in the analysis;

. enumeration of the characteristics that will predict energy transfer on the form of heat;

. accepting that, more than an isolated cause, a sequence of causes is responsible for an effect, and that they need to be properly interrelated;

. distinguishing between changes and permanent states.

As to what concerns the recurrent 'explanations' used to explain phenomena, one must bear in mind some of the arguments that, depending on the degree expected, can fail to achieve their goals. Therefore, given the level of complexity concerning the phenomena, either chosen, either randomly brought in the context of the classroom, some issues must be carefully examined (Rosier and Viennot, 1991). For instance, expansion of solids when heated, as we know that, though molecular vibration increases, still they can remain on the same place without drifting. The same applies to the distinction between heat and temperature, aiming at identifying the extensive character of the first versus the intensive nature of the second concept, the relevant systems and parameters or the nature of changes of state versus heat transfer and changes of kinetic energy.

5.2. Intermediary steps

There are similarities between the spontaneous conceptual ideas of students and the Aristotelian vision of phenomena, with which mankind lived for more than twenty centuries. Among others are those related with kinematic concepts, their relation to forces, the concept of force itself, and heat as a fluid. So, along with the required precision when using terms and concepts during subjects approach and class explanations, it will probably still become important to, using simple situations from day-to-day life and experimental tasks with working groups, accustom the student's mind to be able to live with two interpretations, hoping that ultimately he will choose the one that suits him better. Some work around this theme has been developed by Kaper and Goedhart (2002), as a sort of 'intermediary' step towards thermodynamics. Some of the inconsistencies that classical approaches towards energy have been reproducing for the last half century, such as those that enable students to calculate quantities of kinetic, potential, elastic and electrical energy form and never admits calculating the amount of heat the object 'has' but only the amount transferred, must not be ignored as a source of misconception. In that sense, Kaper and Goedhart (2002) argue that "a reformulation of 'forms of energy' language, so as to allow the calculation of $Q= mcT$, would increase the degree of consistency in the sense of not making exceptions".

6. Results

There are strong expectations that the evolution freshmen's physics and physics based areas of knowledge in the course has initiated, can encompass, both a more diversified syllabus with new subjects, which boosts student's interest and relation with real world, and an always welcomed increased rigor of language, concepts and explanations, enabling a more complete vision of phenomena. In all of the surveys conducted, time was considered to be a major factor. We believe this is concerning time to analyze, to reflect and revisit. To let things settle, as opposed to the habitual instant grasp in today's world. Regular study and class attendance was, gratifyingly for the teacher, recognized as fundamental, which made the department considering the implementation of regular yearlong sessions on study techniques and group behavior. The mood has definitely changed over recent years: a much more open-minded attitude has been noticed by the Physics teachers of first year students. There has been a lively atmosphere when first classes started. Nevertheless, the rate of retention has not revealed a sensible trend towards an increase. Much expectation is placed in restructured lab work.

7. Conclusions

The students' reaction has been moderate, either in what concerns the results in physics and physics based modules, either in the levels of retention, though the collected opinions made by survey are extremely positive, acknowledging the efforts that the department has been achieving in order to enable them to overcome some of their major difficulties. Nevertheless, though the results obtained are modest, they are an encouragement to continue efforts in this direction. Introducing a more complex approach to some explanation routines, ensuring a coverage of a wider number of subjects, using a more diversified and stimulating syllabus and reengineering lab work (which will be the subject of a future paper), while preserving the strong foundation in engineering sciences from the previous one, is the set of measures the department is dealing with. These are operational steps of what we believe to be an opportunity to "develop educational programs that assume that all individuals, not just an elite, can become competent thinkers" (Resnick, 1989) and that "Education has no higher purpose than preparing people to lead personally fulfilling and responsible lives." (Vygotsky, 1986).

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