LET'S DO IT! 1ST YEAR STUDENT'S HANDS-ON PHYSICS PROJECTS

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Abstract. *The following paper aims to describe the new challenges of experimental didactic activities in Mechanics (Physics) in the first year of both Mechanical and Industrial Engineering courses. It is certain that lab work must privilege student's participation, not only to apply studied concepts but also to develop observation, analysis and interpretation skills. A new pedagogical strategy abandoned former written protocols and started implementing lab work by project. Learning by project intensifies cognitive activity, stimulates innovation and creativity as well as promotes team work. Each team of three students had to plan experiments for five different subjects. Those plans were presented and discussed with the instructor in order to evaluate its feasibility. Students were aware of the existing facilities and material in the laboratory, although they could bring something more if necessary. Themes/subjects were: launching projectiles, force and motion, conservation/dissipation of energy, collisions and rotational momentum. During experimental work students faced some technical difficulties. They had to solve them, revealing their knowledge, initiative, capacity of group integration and time management. Each experiment produced a written report. At the end of the semester and after a draw by lot, each student had to present and discuss one of the experiments; this allowed clarifying each one's contribution. These presentations also pointed out communication and discussion skills. The projects were wide-ranging and some of them quite interesting. The main goal this initiative is introducing students to autonomous work by means of routine defiant learning processes that enable them to avoid the pitfalls that have trapped multiple generations of engineering students.*

Keywords: *Engineering Education, Physics, Learning by Project*

1. INTRODUCTION

Higher education in Portugal is following a deep changing process as in all countries which subscribed the Bologna Declaration (Einem,1999). The idea of the creation of a European Higher Education Space was formally presented for the first time in the Sorbonne Declaration (Allègre *et al.*, 1998). It represented the political wish to go further, beyond a mere economic union. Education and knowledge were recognized as vital for Europe's development. There were significant differences between the existing higher education systems inside the different countries of the union. It was time to create the mechanisms to allow convergence, easing mobility for students and teachers in order to share knowledge and experiences, increasing innovation and skill acquisition.

The Bologna Declaration established a strong commitment between governments aiming at building a common educational area and improving transparency and compatibility. It is important to understand that this Bologna Process is the result of multiple reflections and analysis promoted by national and supranational work groups and personalities. From these the need of a paradigm change arises, not only in educational structures, but also in thought and knowledge creation.

The learning process will lead students to acquire personal, academic and professional skills. These skills will play a fundamental role for the individual and for his integration in society. The focus of the learning-teaching process will shift towards the student and his particular progress will serve as a point of reference. This learning and training process is meant to continue throughout life. The importance of a lifelong learning policy is related with employability and adaptability, active citizenship and social inclusion. It also includes the skills, knowledge, attitudes and behaviors that people acquire in their day-to-day experiences.

The definition of the academic and professional profiles will be related to the identification and development of students' acquired skills.

Actually, the Bologna process is aimed at creating a new higher educational paradigm centered on student work, skill importance and preparation for professional life. This goal needs a significant and complex change in mentalities and attitudes, requiring the work and motivation of students and teachers. The pedagogical context is nuclear in this process, namely in which concerns to the adoption of new and dynamic learning-teaching methodologies.

2. THE ADAPTATION PROCESS

As a result of the challenges proposed by this new higher education paradigm, the Mechanical Engineering and Industrial Management Department have undertaken efforts to design a Mechanical Engineering Course that could respond to the new orientations.

Over the last fifteen years, the life span of the Mechanical Engineering and Industrial Management course, there were several measures taken in order to give students the best education for their future professional lives as well as to contribute towards successful promotion of the course.

These measures such as integration, tutorial and socio-pedagogical programs, team working projects, curricula and methodology revisions were taken with very interesting results.

The design and implementation of a new curricular structure as a consequence of the Bologna process was a pretext for a broad discussion within the Department. After a period of some expectation regarding the duration of the different study cycles, it was decided by the government to establish the first cycle (the former bachelor graduation), 180 ECTS (European Credit Transfer System Units), corresponding to six semesters.

This credit system takes into account all the student's work hours: classes, tutorial, preparation and lab experiments and study. In order to have an accurate reference so as to distribute credit units fairly, both students and teachers answered questionnaires. Their opinions about the different kinds of work hours were fundamental to the attribution of the new subject's credits. Consequently, the new degree has five subjects each semester, one less than the former degree. This new course is centered in 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. The adequacy of the course revealed the need to reinforce practical knowledge application, to intensify the use of problem based learning, to design new laboratorial strategies, to promote team work and to develop the fundamental skills in engineering formation.

The new course design also resulted from the analysis of similar courses in reference countries in engineering, such as Germany, the United Kingdom, the United States, France, Swiss, Spain, Denmark, Sweden and Finland. It was compared mainly in terms of duration, curricular plans, credit system units and strategies adopted. The new Mechanical Engineering degree is comparable in structure with the foreign courses analyzed: basic sciences (Maths and Physics), engineering sciences (Mechanics, Materials Strength, Fluids and Energy, Electricity and Electronics, Automation) and industrial management. General skills, critical for professional future, such as analysis and ability to summarize, communication skills, practical and critical sense, time management and team work were also considered activities to be coached and developed throughout the course.

3. THE NEW MECHANICS SUBJECTS

As a result of the adaptation process two new subjects, Mechanics I and Mechanics II became the heirs of the former Physics and Mechanics. Their syllabi were modified and reorganized, in order to allow the necessary skills to be acquired in this important support field. Mechanics I directs to the analysis of mechanical systems based on concepts in kinematics and dynamics. Mechanics II is dedicated to the study of static. It begins with an analysis of the equilibrium of a particle, followed by the study of single rigid body equilibrium and gradually reaches the analysis of more complex structures. Compared to the syllabi of the former subjects, the most relevant modifications at this level were the decision to concentrate the entire static syllabus in Mechanics II and introducing the study of structures, namely regarding internal forces and methods of structural analysis.

Important changes were made in class scheduling. Formerly Physics was held in three 2-hour classes per week, and Mechanics was held in two 2-hour classes. Now both new subjects have 4.5 hours of class time plus 2 tutorial hours. During those tutorial students are totally free to present topics, questions or problems related to their particular difficulties, namely in those concerning lab work. This strategy encourages the possibility of individual progress in study. Each student can establish his own way to develop the required skills.

Despite the new educational context, there is some teaching experience at this level, because developing different strategies to promote success has always been a primary concern in the Department (Marques and Paiva, 2000). These are usually difficult subjects and the students have to be motivated and closely coached.

It has been possible to identify students' major difficulties and misconceptions. One important gap is related to Newtonian mechanics, mainly in kinematics and dynamics. These difficulties arise when students have their first contact with physics at the age of 13 or 14. They manage to pass through all of the following years adopting a symbolic resolution of physics problems, in the sense of recognizing patterns more than thinking about situations and applying laws and concepts. Differently from other physics' subjects, mechanics is a matter which normal people get in contact with from early age, leading to a set of spontaneous and intuitive theories which are, for the most part, completely divorced from scientific (and 'real') reality. This gap is also related to the abstract and non-intuitive nature of mechanical concepts and its complex formality. In a Mechanics course, the student faces a conflict between two different ways of observing the world that surrounds him: one, constructed from spontaneous observations and intuitive explanations; the other, which is a scientific and rational construction that, most of the times, is not perceived as 'logical' at all (Neto, 1998). Each student has his own difficulties and misconceptions, which leads him to a distinguishable learning-teaching path that must be identified.

4. THE CASE OF MECHANICS I

As referred above, kinematics and dynamics are the subjects that presents students considerable more difficulties. For that reason, the developed work along the school term will be presented for the Mechanics I course. Its syllabus is:

1. Physics and Measurement
2. Kinematics of a Particle
3. Dynamics of a Particle
4. Linear Momentum and Impulse
5. Work and Energy
6. Kinematics and Dynamics of a Rigid Body

4.1. Structure of the classes

The classes didn't follow the classic, rigid scheme of separation between theory and its applications. This is a measure that was implemented ten years ago in most Department' courses.

A particular study subject may start with an exposition supported by the use of a power point presentation, based on using the board, or both, but always promoting dialogue and discussion.

In several occasions, a simple experiment can be the starting point to informal interpellation, as the one shown in Fig.1.

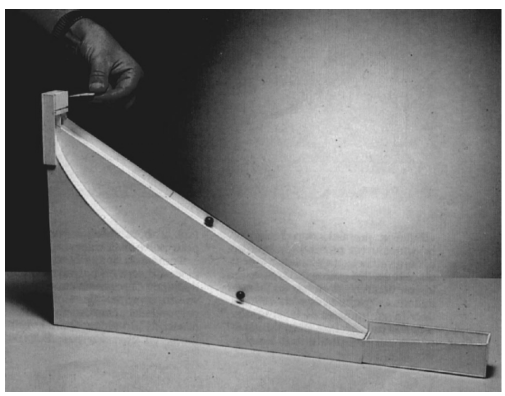


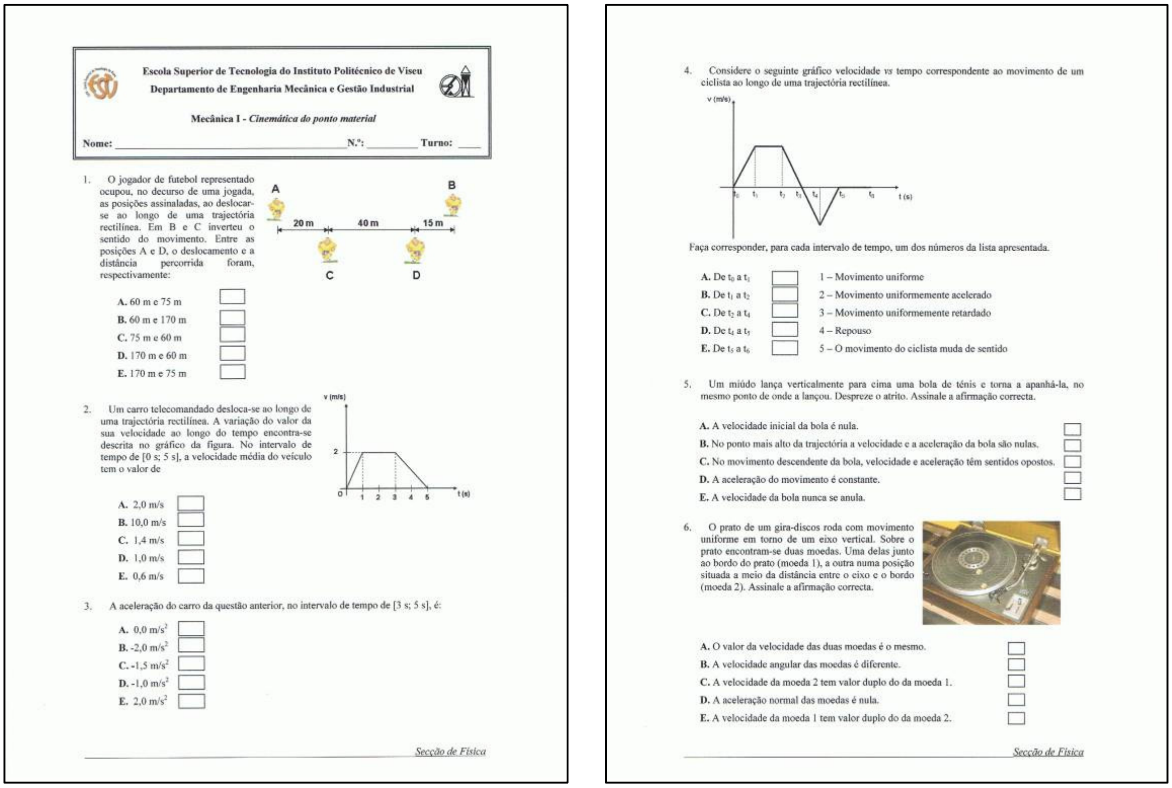
Figure 1. The longest path is the fastest

It also turns out of to be of great importance using simple day-to-day life situations to clarify ideas and to start creating a consistent conceptual structure; examples such as those represented in Fig.2A and Fig.2B are valuable contributions in that sense.

Figure 2A. Newton's laws

Figure 2B. Friction effects

The option for a learning-teaching strategy strongly depends of the students' background related with the course syllabus. As a consequence of their different former academic studies, the groups of students are always very heterogeneous. In order to acquire an initial knowledge about their basic conceptual structure, before beginning the study of each chapter, students must answer quizzes and deliver them handwritten. These quizzes were constructed taking into account the simplest concepts that students should understand. Afterwards, all the questions were discussed and solved in group under the instructor's supervision and participation.



Escola Superior de Tecnologia do Instituto Politécnico de Viseu
Departamento de Engenharia Mecânica e Gestão Industrial

Mecânica I - *Cinemática do ponto material*

Nome: ______________________ N.º: ________ Turno: ____

1. O jogador de futebol representado ocupou, no decurso de uma jogada, as posições assinaladas, ao deslocar-se ao longo de uma trajectória rectilínea. Em B e C inverteu o sentido do movimento. Entre as posições A e D, o deslocamento e a distância percorrida foram, respectivamente:

A B 20 m 40 m 15 m C D

A. 60 m e 75 m
B. 60 m e 170 m
C. 75 m e 60 m
D. 170 m e 60 m
E. 170 m e 75 m

2. Um carro telecomandado desloca-se ao longo de uma trajectória rectilínea. A variação do valor da sua velocidade ao longo do tempo encontra-se descrita no gráfico da figura. No intervalo de tempo de [0 s; 5 s], a velocidade média do veículo tem o valor de

v (m/s) 2 0 1 2 3 4 5 t (s)

A. 2,0 m/s
B. 10,0 m/s
C. 1,4 m/s
D. 1,0 m/s
E. 0,6 m/s

3. A aceleração do carro da questão anterior, no intervalo de tempo de [3 s; 5 s], é:

A. 0,0 m/s^2
B. -2,0 m/s^2
C. -1,5 m/s^2
D. -1,0 m/s^2
E. 2,0 m/s^2

Secção de Física

4. Considere o seguinte gráfico velocidade *vs* tempo correspondente ao movimento de um ciclista ao longo de uma trajectória rectilínea.

v (m/s) t_0 t_1 t_2 t_3 t_4 t_5 t_6 t (s)

Faça corresponder, para cada intervalo de tempo, um dos números da lista apresentada.

A. De t_0 a t_1 — 1 – Movimento uniforme
B. De t_1 a t_2 — 2 – Movimento uniformemente acelerado
C. De t_2 a t_4 — 3 – Movimento uniformemente retardado
D. De t_4 a t_5 — 4 – Repouso
E. De t_5 a t_6 — 5 – O movimento do ciclista muda de sentido

5. Um miúdo lança verticalmente para cima uma bola de ténis e torna a apanhá-la, no mesmo ponto de onde a lançou. Despreze o atrito. Assinale a afirmação correcta.

A. A velocidade inicial da bola é nula.
B. No ponto mais alto da trajectória a velocidade e a aceleração da bola são nulas.
C. No movimento descendente da bola, velocidade e aceleração têm sentidos opostos.
D. A aceleração do movimento é constante.
E. A velocidade da bola nunca se anula.

6. O prato de um gira-discos roda com movimento uniforme em torno de um eixo vertical. Sobre o prato encontram-se duas moedas. Uma delas junto ao bordo do prato (moeda 1), a outra numa posição situada a meio da distância entre o eixo e o bordo (moeda 2). Assinale a afirmação correcta.

A. O valor da velocidade das duas moedas é o mesmo.
B. A velocidade angular das moedas é diferente.
C. A velocidade da moeda 2 tem valor duplo do da moeda 1.
D. A aceleração normal das moedas é nula.
E. A velocidade da moeda 1 tem valor duplo do da moeda 2.

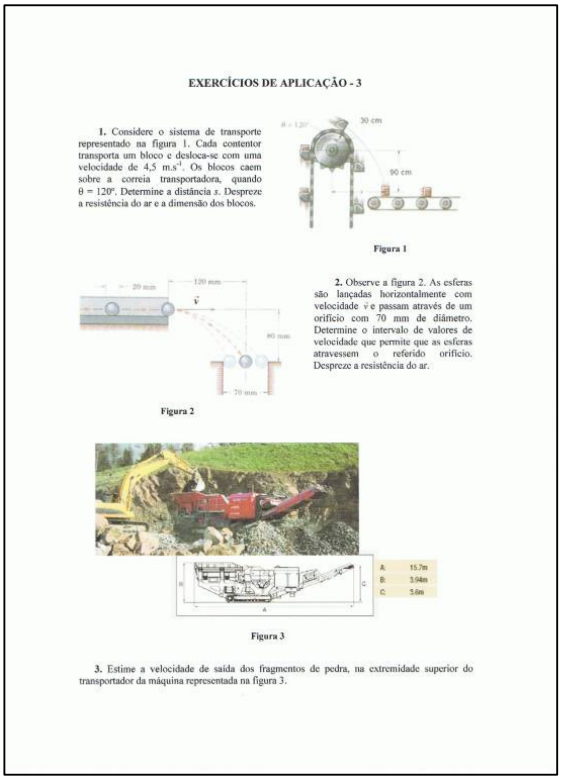
Secção de Física

Figure 3. Example of a quiz

Abandoning the separation between theory and its applications conducts to an interesting dynamic in class. Sets of questions, exercises and problems were selected since the beginning of the term, covering syllabus, which allows various possibilities in choosing the most adequate for different pedagogical situations, complementing theoretical approaches. The students were invited to solve some of those questions, exercises and problems during classes, individually or within teams, and all the remaining were assigned as homework. They also had the possibility to use tutorial sessions to make questions in order to achieve or verify solutions and were invited as well to share their experiences while trying to solve them. Some interesting discussions revealed common misconceptions. Electronic mail was also available to establish bridges between the instructor and students. Quite often they required answers and got new questions in return, as clues to help them to make their own way through the resolution.

4.2. Homework problems

These homework problems were created at the end of each semester's week and sent to students by electronic mail. They aimed at reflecting some aspects that, in the instructor's own opinion, could not have been sufficiently understood during classes and tutorial. They also meant to establish a more effective connection with real engineering situations, improving knowledge and at the same time increasing motivation. Students were invited to perform written resolutions. They could clear up any doubts using electronic-mail or tutorial. The resolutions were delivered to the instructor for correction within a week and were discussed with each student (sometimes in group), when considered relevant.



EXERCÍCIOS DE APLICAÇÃO - 3

1. Considere o sistema de transporte representado na figura 1. Cada contentor transporta um bloco e desloca-se com uma velocidade de 4,5 $m.s^{-1}$. Os blocos caem sobre a correia transportadora, quando $\theta = 120°$. Determine a distância *s*. Despreze a resistência do ar e a dimensão dos blocos.

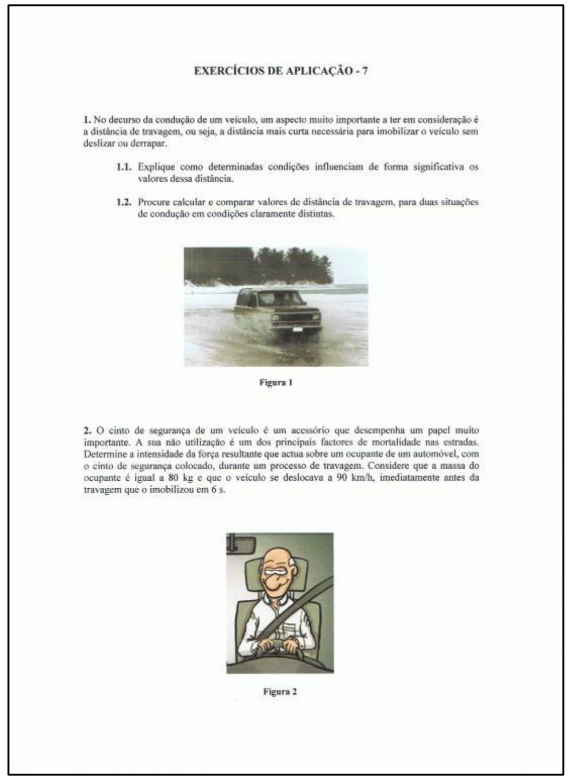
Figura 1

2. Observe a figura 2. As esferas são lançadas horizontalmente com velocidade $\vec{v}$ e passam através de um orifício com 70 mm de diâmetro. Determine o intervalo de valores de velocidade que permite que as esferas atravessem o referido orifício. Despreze a resistência do ar.

Figura 2

Figura 3

3. Estime a velocidade de saída dos fragmentos de pedra, na extremidade superior do transportador da máquina representada na figura 3.



EXERCÍCIOS DE APLICAÇÃO - 7

1. No decurso da condução de um veículo, um aspecto muito importante a ter em consideração é a distância de travagem, ou seja, a distância mais curta necessária para imobilizar o veículo sem deslizar ou derrapar.

1.1. Explique como determinadas condições influenciam de forma significativa os valores dessa distância.

1.2. Procure calcular e comparar valores de distância de travagem, para duas situações de condução em condições claramente distintas.

Figura 1

2. O cinto de segurança de um veículo é um acessório que desempenha um papel muito importante. A sua não utilização é um dos principais factores de mortalidade nas estradas. Determine a intensidade da força resultante que actua sobre um ocupante de um automóvel, com o cinto de segurança colocado, durante um processo de travagem. Considere que a massa do ocupante é igual a 80 kg e que o veículo se deslocava a 90 km/h, imediatamente antes da travagem que o imobilizou em 6 s.

Figura 2

Figure 4. Examples of homework problems

4.3. Lab work structure

One of the components that integrate the Mechanics I course that needed deep reform was the laboratory, mainly concerning lab classes.

Former written protocols were abandoned. These were elaborated by the instructor and gave a rigid orientation, leaving no place to students' creativity. Quite often students didn't prepare their work properly and were passively following protocols. Although being 1st year students with little lab experience, the new learning-teaching paradigm clearly pointed in another direction. A new challenge was being proposed to the students. They would have to create and implement experiments by themselves using the Physics lab facilities. If they considered it to be necessary, they could bring some simple and common material from home. Those experiments should cover five main items of the syllabus: projectile motion, force and motion, conservation/dissipation of energy, physics of collisions and rotational dynamics. The goal was to implement, in laboratorial classes, a learning by project strategy, intensifying cognitive activity, stimulating innovation and creativity as well as promoting team work (Guedes *et al.*,2007).

4.3.1. Building a project

Following this new strategy, students were informed at the beginning of the term about the subjects that experiments should incorporate; they also had a first contact with the existing lab material. Next, they were invited to create teams of three. Each team had to design five different projects for five different experiments. A month established as the limit to present plans for the experiments. During that period , students had to imagine what kind of experiments they wanted to perform, they had to clarify objectives and select laboratorial material, doing the necessary research. Written plans with the description of the experiments, their objectives and corresponding laboratorial material were delivered to the instructor.

After the instructor analyzed the plans, they were discussed with each team in order to clarify or modify some of the proposals. Sometimes they were technical unfeasible, most of the times due to the lack certain lab devices. In other situations there was the possibility to simplify procedures. In any case, the instructor always tried to make questions more than suggestions. The most part of the corrections were proposed by students as a consequence of their own individual and/or in group reflection and discussion.

Two examples of student team's projects are described:

1. Force and motion

The idea was to use a Physics lab device that consisted of a path along which a vehicle could be moved by the action of a falling mass suspended by a string and a pulley system, as can be observed in Fig. 5A. The mass fall can be stopped with the use of a break system. A sensor fixed at the beginning of the path, connected to an acquisition system and a computer, allows the registration of position, velocity and acceleration, as shown in Fig. 5B. Data can be worked in distinct ways, highlighting a set of concepts and measurable values. Using different conditions, there is a lot of possibilities to explore.

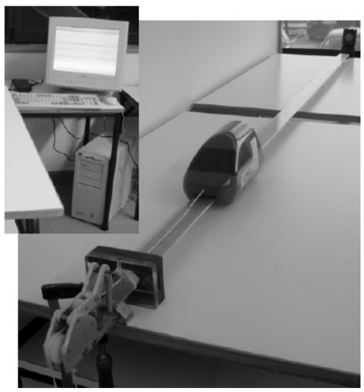


Figure 5A. Vehicle device

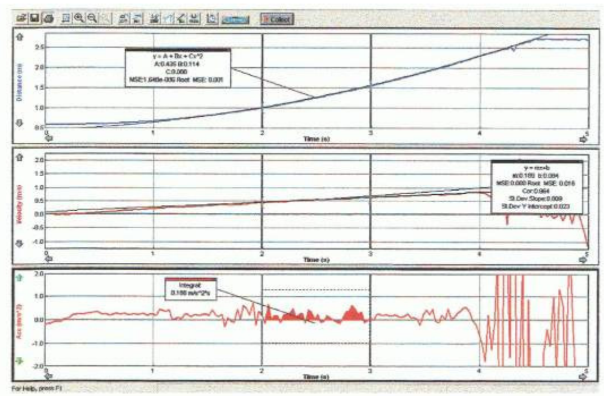


Figure 5B. Motion graphics

Using a chosen suspended mass, this team proposed to:

i) Calculate the resultant force which acted on the vehicle;
ii) Quantify friction during motion;
iii) Measure the final speed;
iv) Measure the stopping time of the vehicle after break use;
v) Calculate the stopping distance.

As a result of the instructor's analysis followed by a discussion, the team was able to realize that it was technically impossible to measure friction force during motion, but only verify its existence. The students could also explain that when they referred final speed, their intention was to measure the vehicle's speed at the instant before break's action. In which concerned all the other points, their experiment plan was feasible and interesting. Student difficulties using position, velocity, and acceleration versus time graphs are quite common. They also include, among others, graphical interpretation, the inability to understand the meaning of the area under different graph curves or to establish a correct relation between kinematics quantities and applied forces (Almeida, 2004).

2. Rotational dynamics

This proposal was based on the use of a rotation experiments apparatus, as it can be seen in Fig.6, which consists in a turntable with an inner shaft, where a cord is attached. A mass can be suspended by the cord around the inner shaft. When the mass is released from rest it causes the rotational motion of the system.

Figure 6 – Rotational apparatus

This device allows a considerable set of experiments about kinematics and dynamics of rotational motion, a subject that usually students consider of great difficulty. The different physical concepts they are related with cause a lot of misconceptions. This subject experiments always help to clarify some ideas.

This team planned to study the role of moment of inertia in rotational motion. They proposed the use of a tennis ball and a roller hockey ball, brought from home, to perform the experiment. Their first idea was to put each ball at the centre of the turntable and for each situation they would measure the time that propulsion mass needed to reach the floor. Using those values they could calculate and compare the moments of inertia of the two balls. After some discussion they added to their plan the calculation of those moments of inertia based in the masses and dimensions of the balls and the comparison with the corresponding experimental values.

It is important to refer the quality of the most part of the plans, namely in their innovation content as well as in the well defined objectives. It was also very interesting to observe the capacity that students revealed while justifying their options and during the search of technical alternatives. The discussions allowed improving discussion skills, creativity and autonomous learning in a team work interaction.

4.3.2. Working in the lab

Laboratorial implementation of different experiments lead students to face and solve some technical problems, which was normal in these situations. Most part of the students already had some lab contact in high school, as a result of directed experiments based in protocols or from observation of teacher's laboratorial performance in classes. But due to this new strategy they were following their own plans, applying concepts, using selected laboratorial materials, interacting in group, managing time, all in order to achieve the goals that they had established themselves. The search for explanations for these lab situations is an important contribution to understanding mechanics.

The teacher interacted with all the work teams. He always stimulated the search of solutions, gave clues that allowed students to find answers to their questions inside their own teams, promoted reflection during the experiments and about the results obtained. He also could follow students' evolution with respect to acquisition skills in applied knowledge and experimental work. At the same time he could observe students' behavior as active members of a team, the way they planned, organized and managed the different steps of their work.

4.3.3. The written reports

The teams had to produce written reports concerning all performed experiments. The reports were also the result of team work because each team delivered one single written report for each experiment. At the beginning of the term some information was distributed about reports, namely concerning their recommended structure. Rigorous time schedules were defined. Each report should be delivered one week after the laboratorial work was done.

The reports reflected different aspects of students' progress. The teacher could evaluate effective comprehension of concepts, skills to deal with experimental data analysis and to reach supported conclusions. Good writing could also be evaluated.

4.3.4. Public presentation and discussion of the experiments

At the end of the semester and as a result of a draw by lot, each student had to present and discuss in public one of the performed experiments. The students had four weeks between the draw and the presentation day. The strategy and structure of the presentations had no specific rules, with the exception of time duration: twenty minutes maximum, including questions and discussion. Each one was totally free to choose how to do it. Students used different supports to present their work: power point slideshow, power point slideshow and board writing, board writing, oral communication based in lab devices and simple oral communication. This is an important issue because, on the one hand, students have to reflect about the concepts involved, the results obtained and conclusions drawn; on the other hand, they can develop skills related to analysis, synthesis and communication such as the correct use of language and the adequate behavior facing an audience, to name only a few.

After each presentation, the instructors conducted the discussion, asking some questions. The other students could also participate in the discussion but no one did it.

The discussion allowed observing communication and discussion skills. They also complemented the analysis and evaluation of individual work inside the team.

4.4. Assessment

Assessment of Mechanics I covers the different issues of students' work and also pretends to motivate class attendance and quality participation, which is considered of major importance (Marques and Paiva, 2000). Assessment is a very complex matter and the actual distribution of values is certainly not perfect. At the beginning of each semester there is always a reflection and a discussion point, opened to changes, as a result of accumulated experience. For the moment being, the weights are divided as shown in Tab. 1.

Table 1. Mechanics I course assessment.

Issue	Value (%)
Written exam	58.5
Laboratorial work	18.0
Control tests	13.5
Attendance and quality participation	10.0

The aim in attributing a higher weght to lab components is being analysed. This new strategy's first results are very positive and can promote changes. Also, control tests may have a higher value. These tests (usually three or four) are proposed during the semester and allow the students' progress control, not only for the instructor but also for the students themselves. On the other hand, the weight of the final written test will probably be diminished.

It is important to refer that a record of attendance is in place. In order to assess the quality of participation, the instructor takes into account the performances in classes, tutorial and homework.

5. RESULTS

A first evaluation was made after the end of the term and before the written exams period. It consisted of an individual semi-structured interview. During these interviews students were asked to give their opinion about the Mechanics I course in general and to answer to direct questions related to the new strategies, namely in lab work.

Their opinions were very positive. All of them agreed with the present methodology and considered it as being much more stimulating; they also considered that it allowed an autonomous and deeper learning which was not acquired when the former protocols were in place. Some students' translated comments can transmit a more precise idea about their thoughts:

"It's easier to understand subjects."
"It's much more interesting, because it was our idea."
"The lab work became more simple and understandable."
"We designed something and we were able to do it."

Related with the new lab work and homework problems is the tutorial's attendance issue. Effectively, as a consequence of Bologna's adaptation, the goal is to center the learning-teaching process on student work and individual evolution. This requires a great change in the established mentality, which will probably need some motivational pressings.

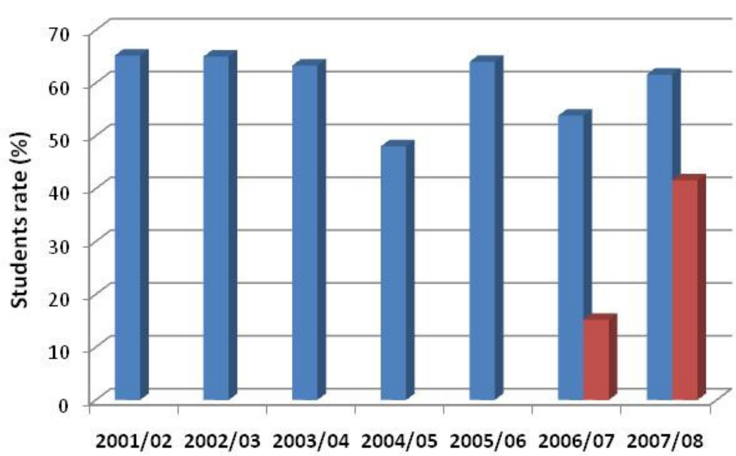


Figure 7. Students' attendance rate: classes (filled) and tutorial (blank); Physics (2001-2006), Mechanics I (2006-2008), after Bologna's adaptation and with tutorial.

During the first year working with Bologna's guidelines, tutorial attendance rate was very low. The new implemented strategies increased considerably tutorial attendance.

6. CONCLUSIONS

At the moment the obtained results are insufficient to draw significant conclusions. There are, nonetheless, some interesting aspects that can be pointed out:

1. Student's active role in the learning-teaching process clearly contributes to important skills development, as it appears to happen in this new laboratorial work strategy.
2. There is an increase of motivation and in students' autonomous work.
3. Change is possible, establishing an end to passive attitudes, helping students to find their own way to success.

Implementation of the Bologna process has been, so far, an excellent opportunity for all those who feel that teaching is finding ways to deliver, to use their ability to put into practice the unified complete set of engineering laws applied to graduated engineers: being able to solve problems independently.

This is a real opportunity to give students a major role in their own learning process, making them responsible for following subjects, creating situations that carry with them important motivating potentials.

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