Real Work in Physics Classroom: Improving Engineering Students Competences

Clara Viegas
Instituto Superior de Engenharia, Porto
mcm@isep.ipp.pt

J. Bernardino Lopes[1], José Cravino[2]

Abstract – **Traditionally, in physics teaching, an appreciable time is spent developing exercises on the blackboard, in which students do little work. We present an alternative approach, based on physics education research, taking into consideration the Bologna's perspective to actively involve students and specially oriented to develop certain important competencies in engineering students. Basically, it uses collaborative work and tasks done by the students to promote the development of competencies. Autonomous work and student's responsibility were also promoted. 7 classes with different teachers had different degrees of proximity to this curriculum re-design. Will this competence development approach affect the students' final evaluation? And if so, will it benefit the majority of the students? How do students' perceive this new approach and how comfortable they feel with it? The results, generally considered, show that the efforts contribute to more effective teaching producing progressively better academic results (pass rates and final marks) and students recognize progressively better teacher mediation. On the other hand, in classes where the learning environment was based on autonomous real work, solving complex real problems, diversified teacher mediation and centered on student work, the academic results were equal or even better than those whose classes presented a more traditional approach. In addition, a larger number of students increased development of high-level competences.**

Key Words - Collaborative work, Competences, Mediation, Physics learning, Physics teaching.

INTRODUCTION

This work is part of a curriculum re-design, based on research in physics education, which is being developed in an introductory physics course in an engineering school of Northern Portugal. This curriculum has the goal of improving students' competences in their daily work with the physics subject matter and its connections with daily life.

In real life a professional engineer is evaluated by his performance and competence, and is asked to act in different and complex situations that involve analyzing, interpreting and anticipating results, and he should be prepared to do so in college [1]. This will only be accomplished if knowledge becomes operative [2]. For this to happen students must work with knowledge so that it becomes meaningful. Therefore, learning should be directed to the development of competencies that will improve professional performance. Even though this concern is somehow present in the senior years, it is not common in the introductory and basic courses of the early years, in which the principal concern is to cover the subject matter as stated in the syllabus [3, 4] and provide enough information for the students to carry on.

A quick review on the state of the art in educational research points to the need for active learning [4-8] in promoting the students participation and responsibility. There are several efficiency factors in Physics Education Research involving permanent interaction between students and between students and the teacher [6, 9-13], and point to the importance of mobilizing the prior knowledge in order to construct a more solid one [14]. All this can be accomplish in classroom using collaborative learning [15, 16], developing project work [17-19], tasks to be accomplished by the students [8, 20] associated with permanent and adequate mediation by the teacher [8, 21].

Taking into consideration the Bologna's perspective [22, 23] of making the students' active in their daily class and in improving their capability of autonomous work and responsibility, we present an alternative approach on the traditional exercise solving classes (known as theoretical-practical classes in Portugal and recitation classes in the US literature). Traditionally used to developed complex exercises (often, purely academic) that involve mainly mathematical skills, sometimes not yet well dominated by students, the work of students may end up reduced to making a poor transcription of what the teacher writes in the blackboard. Even though some students seem to learn well in this environment, unfortunately this is not the case for the majority of them. In the new learning environment, more challenging to the students, they are involved from the beginning in developing social and individual competencies. Learning becomes dynamic and the fundamental role is what students develop and accomplish by themselves [4, 7, 8].

The question is if this competence development approach will affect the final marks? And will it benefit the majority of the students? How do students' percept this new approach and do they feel comfortable in it?

[1] J. Bernardino Lopes, Universidade de Trás-os-Montes e Alto Douro, blopes@utad.pt
[2] José Cravino, Universidade de Trás-os-Montes e Alto Douro, jcravino@utad.pt

METHODS

This work involves an analysis of the last four school years in the same course, taught during the first semester. The first year represented (2003/04), was before the teaching intervention and in the two subsequent years several modifications began to take place in order to test the applicability of some efficiency factors found in a literature review on physics education. In 2006/2007 some of these changes were incorporated and integrated in a framework for curricula development and management in the classroom. In table I it is shown the schematic development of the course over the years.

TABLE I
SUMMARY OF THE MODIFICATIONS MADE TO THE THEORETICAL-PRACTICAL CLASSES

Dimension	2003/04	2004/05	2005/06	**2006/07**
Synchronism with theoretic lessons	1/2 weeks	1/2 weeks	1 week	no displacement
Students' Tasks	Individual work on the exercises. 2-3 Tests.	Individual work on the exercises. Weekly paper homework. Weekly e-learning task.	Autonomous work on the exercises. Weekly paper homework or e-learning task.	Project work. Autonomous collaborative work on the exercises. Weekly e-learning homework.
Teacher Mediation	Solving exercise on blackboard. Normal office hours for student consultation.	Prompt support during class. Normal office hours for student consultation. General feedback on homework and on e-learning tasks.	Collaborative discussion on the open problems. Prompt support during class. Normal office hours for student consultation. Feedback on the homework.	Collaborative discussion with the teacher supervision. Prompt support during class. Weekly feedback on the e-learning homework. Office hours consultation suggested by the teacher to each student.
Contribution to the final mark (remaining % goes to final examination mark)	15% (tests)	20% (homework and e-learning tasks)	10% on assiduity and class participation. 10% homework.	15% Project. 10% homework. 5% class participation.

Two teachers-researchers and a group of teaching assistants that changed every year developed this work.

The type of problems proposed to the student's also changed, becoming less dependent of the students mathematical skills and more contextualized and focused on using the students' competence, where they needed to know what was at stake and figure out the solution by themselves. This is exemplified in Table II, where some examination questions form 2003/04 and 2005/06 are indicated as an example. The structure of the exam itself also suffered considerable modifications: previously (in 2003/04) it was divided in two parts: theoretical (with 3 questions) and practical (with 4 problems), with no separate minimum grading requirement. Last year we proposed an exam divided in 3 parts: theoretical (with 9 questions), practical (with 4 problems), each with the minimum grade of 3 values (in 20) and a laboratorial question.

TABLE II
EXAMINATION QUESTIONS EXAMPLES

2003/04

Theoretical question (2 values in 20):

A particle of mass m, moves along X axes under the influence of a conservative force field, being E_p his potential energy. If the particle is in the positions x_1 and x_2 at the instants t_1 and t_2, respectively, prove that if E is the mechanical energy, then:

$$t_2 - t_1 = \sqrt{\frac{m}{2}} \cdot \int_{x_1}^{x_2} \frac{dx}{\sqrt{E - E_p}}$$

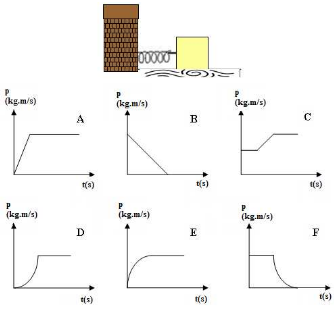
Practical question (3,5 values in 20):

A particle vibrates in a simple harmonic motion with the frequency of 100Hz and 3 mm of amplitude.
a) Calculate its velocity and acceleration at the middle of the trajectory and at the extremes.
b) Write an equation that expresses the displacement as a function of time, knowing that at the initial instant the particle left at the position –1,5mm, moving towards the negative extreme of the trajectory.
c) In which subsequent instant is the velocity maxim?

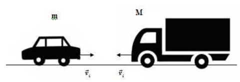
2006/07

Theoretical question (1 value in 20, each):

1) The body of mass m_0 is put against a compress spring. When the spring is released, the body m_0 moves forward without friction. Justify which of the following graphics represents the variation of the body linear motion in time?



2) A 14 ton truck frontally collides with a 2 ton's car (see the picture). Comment the following statements:



A. The force the truck exerts on the car is considerably greater than the one the car exerts on the truck.
B. The acceleration each one suffers is different.
C. During a real collision of this kind, we can always assume a perfect elastic collision.

Practical question (3 values in 20):

A particle is suspended from the ceiling of an elevator through a spring and is at rest relatively to it when the elevator descends with a constant velocity of 1,5 m/s. The elevator then stops suddenly, leaving the particle oscillating with an angular velocity of 2 rad/s. Disregarding the spring's mass, can you determine:
a) The amplitude of the particle's oscillation?
b) Which will be the motion equation of the particle? (Choose the positive axis up)

Now we describe what was done in 2006/2007. The main modification was the collaborative and autonomous work performed by the students. In each lesson they developed a different task towards their final project: "The functioning of an elevator". This project provides an integrative vision of the course and provided stimulation to the collaborative work in class, and their continuation afterwards. In these TP classes the students also discussed and resolved a few problems and more classic exercises.

No synchronism was imposed on the different groups work; in fact each group worked at their own pace, achieving their own goals, developing autonomy and responsibility. Respect for their colleagues and their ideas were promoted, in order to include everyone in the daily work.

Additionally, on a weekly basis, each student would have to perform a related e-learning task, in order to infer the success of his own individual achievements. The teacher's role was to mediate this individual and group achievements, namely in discussing certain issues at crucial moments, encouraging their performance and giving them permanent feedback of their developments, including in the homework which has individual weekly feedback. When significant difficulties emerged, a personal consultation would be scheduled with the student for an out of class office meeting with the teacher.

The universe in study represents 216 diurnal students which were split over 7 classes, with slightly different teaching methods, taught by the different teachers: AB and GH classes followed the proposed methodology, KL and NV classes followed a more traditional teaching methodology, and the other classes followed a mixed strategy, in which the teacher sometimes did solve some of the problems in the blackboard. In order to realize if these differences contributed a significant difference in the results, we analyzed the achievements in all classes separately. The instruments used to collect data were: the curricula materials; a questionnaire at the end of the course; the QEAME [18, 24], with a set of questions about students' perception about classes; interviews to students and to teachers; competence test.

RESULTS

We present the results in two different perspectives: (i) the evolution of results accomplished over the years, (ii) the comparison of the impact of slightly different curriculum approaches in the development of students' competences and knowledge.

I. Global analyses over the years

Comparing the final marks of students over the years (Figure 1A and 1B), it is clear that there is a decrease in lower marks (SM). The number of students failing the course has also been decreasing, even though the number of students who try to complete the course has been decreasing as well. It is possible that the adequacy of the course to the Bologna Process, which will occur next year, may be responsible for this decrease in enrolment (due to the expected equivalences in courses).

If only the students who have tried to complete the course are taken under consideration (that is, not considering the students who did not attend the minimum number of lessons, nor those who did not take any of the two final exams) it is clear that the numerical marks have improved, specially in this last year, as shown in the Figure 2 by the numerical marks distributions (over 8 values).

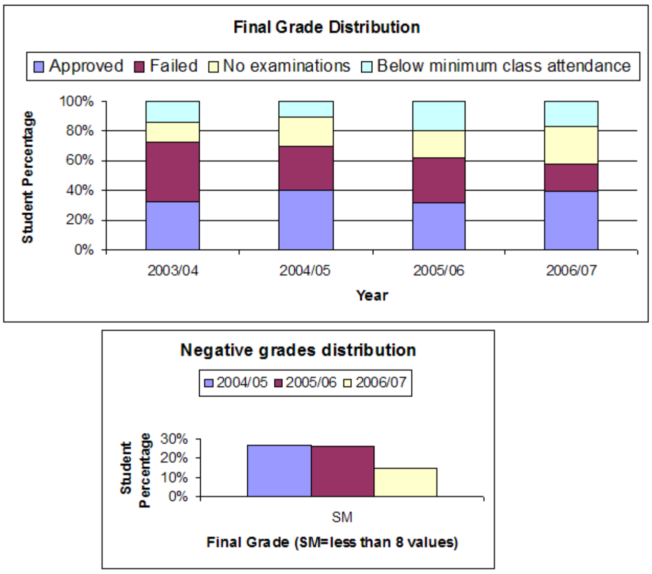


FIGURE 1
A - STUDENTS' FINAL STATUS DISTRIBUTION.
B - STUDENTS WITH MARKS BELOW 8 (0-20 SCALE).

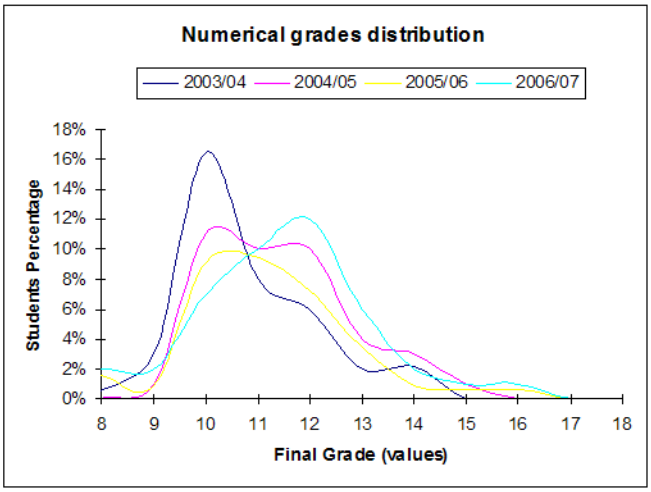


FIGURE 2
FINAL RESULTS DISTRIBUTIONS THROUGHOUT THE YEARS.

At the end of the course, students answered an anonymous questionnaire (QEAME) in the e-learning platform. We compared the results (36 responses) with the ones obtained last year (33 responses). There is an increased in all the dimensions [18] significant to this study (Table III).

The last three indicators of the table III are related to the quality of teacher mediation, as perceived by students. It is clear that students recognize an improvement of mediation quality from 2005/2006 to 2006/2007.

TABLE III
MEDIAN RESULTS OBTAINED IN A LIKERT SCALE (1 TO 5) OF AGREEMENT (QEAME)

Dimension	2005/06	**2006/07**
Deliberated effort towards good teaching	3,5	4
Permanent Evaluation	2,5	2,9
Permanent Interaction	3	3,4
Stimulus to the student independence	2,3	2,7

In teachers and students interviews, it became clear that students appreciate solving the problems by themselves, but were uncomfortable with the amount of work performed in class, referring they would rather like an intermediate solution, with the teacher solving some problems, so they would not loose so much time with it and could get more work done, that they thought was needed to get them prepared for the exam. Some of the teachers ended by doing just that, when they felt the students needed more help. Nevertheless all teachers refer that, in general, motivation in class increased, and the discussions in class were more or less participated by everyone. Another fact pointed out by the teachers was the low attendance of students in their scheduled appointments or in the personalized meetings. Some students refer they primarily seek out a colleague rather than the teacher to resolve regular doubts, and resort to the teacher only if this first resource failed. This effect is reported in the literature [25], but it maybe increased by the social competencies developed in classroom and the permanent discussion the students enrolled with each other.

II. Analysis of the success of the different curriculum approaches in 2006/07

In figure 3 we can see that GH class has the best pass rate and lower abandonment rate.

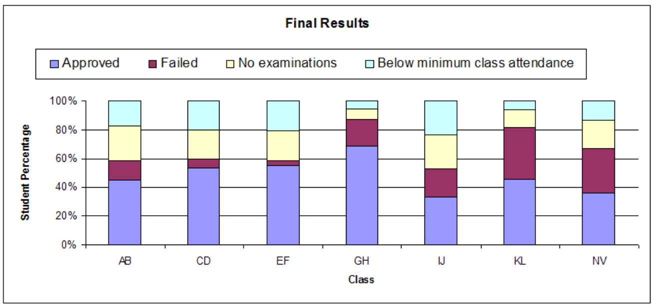


FIGURE 3
FINAL RESULTS DISTRIBUTION

Figure 4 shows the results of a detailed analysis of the competences test performed by the students. This test involved the competences to interpret, establish relations and deduct consequences in a real situation.

In general the percentage of students who did not even try to solve the question, or in doing so did not get any tangible result, is very high, which indicates the relative difficulty students still feel in this type of questions. Nevertheless the best result is obtained in GH class. The others levels of competences results are: second level -KL class; third level, -AB, IJ, and NV classes; forth level - CD, and EF classes.

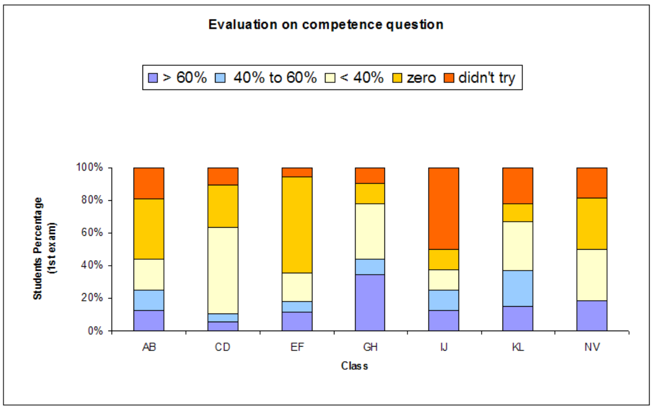


FIGURE 4
DISTRIBUTION ON THE RESULTS OBTAINED IN A COMPETENCE QUESTION

It was also evaluated the number of students in each class that achieved more than 13 (in a 0-20 scale) and those who did not achieved more than 5 values (Figure 5). In this comparison, students in classes AB and GH clearly perform better. In the KL class there was a clear teaching problem because there are a significant number of students who did not achieve more than 5 in a scale of 0 to 20.

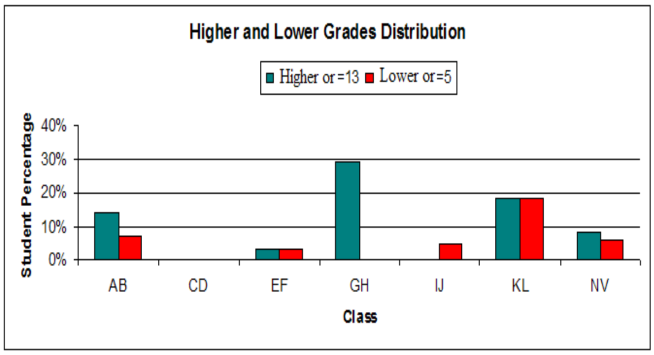


FIGURE 5
HIGHER AND LOWER GRADES COMPARISON.

DISCUSSION AND CONCLUSIONS

The academic results point clearly to an increase of success in the course from year to year, as measured by the final marks. There is also an improvement in the fact that the incidence of students with very low marks, and failing marks in general, has been significantly decreased. Also the pass grade results show substantial improvements, with a large percentage of good grades. The results, generally considered, show that the efforts contribute for a more effective teaching, producing academic results that are progressively better (pass rates). This result is consistent with the one that indicates progressively better teacher mediation, as perceived by students.

Even though students recognized the learning environment and described it favorably, we felt some resistance in some of them to adapt to these active learning methods, in which the amount of student work being done during class and out of class is increased. Some students revealed an increase in their motivation, developed important competences in cooperative work and reported that the teachers feedback was important to overcome some difficulties during the course.

On the other hand, the results clearly support that, in classes where the learning environment was based on autonomous real work, solving complex real problems and teacher mediation was diversified and centered on student work:

(i) The academic results were equal or even better than those whose classes presented a more traditional teaching approach;

(ii) High level competences were better developed in a larger number of students than those whose classes presented a more traditional approach.

This claim is true even though this learning environment was not yet well accepted by all students. This fact may suggest the possibility of greater developments either in the students with more difficulties and in those who were already better prepared.

An important question for future work is if these active methods even though they demand permanent teacher supervision and feedback, are applicable in larger classes as well as in smaller ones. These preliminary results point to greater achievements in larger classes, but more data is needed to analyze this more accurately in the future.

In summary, our results show that students do achieve better results and higher level of competencies if they enrolled in real work in class, mostly collaborative work, and being more motivated to continue the work out of class.

ACKNOWLEDGMENT

We acknowledge the support of the Polytechnic Engineer School of Oporto (ISEP) and of the Civil Engineering Physics I Course staff and students that over the past three years were involved in this study.

REFERENCES

[1] P. Perrenoud, *Porquê construir competências a partir da escola?* 2ª ed. Porto: ASA Editores, S.A., 2003.

[2] J.-P. Astolfi, *L'école pour apprendre*. Paris: ESF, 1992.

[3] M. d. C. Roldão, *Gestão do Currículo e Avaliação de Competências*, 1ª ed. Lisboa: Editorial Presença, 2003.

[4] E. Redish and R. Steinberg, "Teaching Physics: Figuring Out What Works," *Physics Today*, vol. 52, pp. 24-30, 1999.

[5] E. Mazur, *Peer Instruction, a user's manual*. New Jersey: Prentice Hall, 1997.

[6] D. E. Meltzer and K. Manivannan, "Transforming the lecture-hall environment: The fully interactive physics lecture," *American Journal Of Physics*, vol. 70, pp. 639-654, 2002.

[7] R. M. Felder, D. R. Woods, J. E. Stice, and A. Rugarcia, "The Future of Engineering Education II. Teaching Methods that Work," *Chem. Engr. Education*, vol. 34, pp. 26-39, 2000.

[8] J. B. Lopes, *Aprender e Ensinar Física*. Lisboa: Fundação Calouste Gulbenkian, 2004.

[9] C. Crouch and E. Mazur, "Peer Instruction: Ten Years of Experience and Result," *Am. J. Phys.*, vol. 69, pp. 970-7, 2001.

[10] R. Hake, "Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.*, vol. 66, pp. 64-74, 1998.

[11] G. M. Novak, E. T. Patterson, A. D. Gavrin, and W. Christian, *Just-in-time teaching: blending Active Learning with web technology*. NJ: Prentice Hall, Upper Saddle River, 1999.

[12] P. Ramsden, "Improving Teaching and Learning in Higher Education: the case for a relational perspective," *Studies in Higher Education*, vol. 12, pp. 275-286, 1987.

[13] E. F. Redish, *Teaching Physics With the Physics Suite*. USA: John Wiley & Sons, Inc., 2003.

[14] A. B. Arons, *Teaching Introductory Physics*. USA: John Wiley & Sons, Inc., 1997.

[15] H. Gijlers and T. d. Jong, "The relation between Prior Knowledge and Students' Collaborative Discovery Learning Process," *J. of Research in Science Teaching*, vol. 42, pp. 264-282, 2005.

[16] P. Heller, R.Keith, and S. Anderson, "Teaching problem solving through cooperative grouping. Part1: Group versus individual problem solving," *Am. J. of Phys.*, vol. 60, pp. 627-636, 1992.

[17] B. Bell, "Pedagogies developed in the Learning in Science Projects and related theses," *International Journal Of Science Education*, vol. 27, pp. 159-182, 2005.

[18] J. P. Cravino, "*Ensino da Física Geral nas Universidades Públicas Portuguesas e sua Relação com o Insucesso Escolar - Caracterização do Problema e Desenho, Implementação e Avaliação de uma Intervenção Didáctica*," vol. Tese de Doutoramento. Vila Real: Universidade de Trás-os-Montes e Alto Douro, 2004.

[19] E. Hewton, "Project Work in Universities," *Physics Education*, 1975.

[20] M. Kearney, "Classroom Use of Multimedia-Supported Predict-Observe-Explain Tasks in a Social Construtivist Learning Environment," *Research in Science Education*, vol. 34, pp. 427-453, 2004.

[21] S. E. Hampton and R. A. Reiser, "Effects of a theory-based feddback and consultation process on instruction and learning in college classrooms," *Research in Science Education*, vol. 45, pp. 497-527, 2004.

[22] G. Gordon, "Comparability of postgraduate academic qualification: Some issues, challenges and experiences," *Higher Education*, vol. 40, pp. 377-388, 2000.

[23] CESEAR and SEFI, "Engineering Education and Research and the Bologna Process - On the Road to Bergen 2005." Belgium, 2005.
[24] P. Ramsden, "A Performance Indicator of Teaching Quality in Higher Education: The Course Experience Questionnaire," *Studies In Higher Education*, vol. 16, pp. 129-150, 1991.
[25] P. Gorsky, A. Caspi, and R. Trumper, "Campus-based university students' use of dialogue," *Studies In Higher Education*, vol. 31, pp. 71-87, 2006.