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Improving the Learning of Physics and Development of Competences in Engineering Students*

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Engineering students should start being prepared for the demands of their profession from the early introductory courses. However, introductory physics courses often have little connection to the real world of engineering. Our work proposes a way towards meeting this objective: first, by a carefully planed curriculum, which must clearly inter-relate the desired learning outcomes with contextualized real-world tasks, and aligned with the students' assessment; second, by a careful mediation of the students' learning in the classroom, stimulating a healthy social learning environment, where students develop real work and overcome natural difficulties in order to construct their knowledge and develop the intended competences and abilities. This work took place in a Portuguese Polytechnic School of Engineering during four years; the results point to an incremental improvement, not only in the historically low pass rates, but also in students' satisfaction. In those classes where teacher mediation was varied and more significantly used to address the needs in students' learning, the results point also to the development of higher level competences.

Keywords: introductory physics; engineering education; teacher mediation; students' learning; students' competences

1. INTRODUCTION

A PROFESSIONAL ENGINEER is evaluated by performance and competence in different and complex situations that involve analysing, interpreting and anticipating results. College should prepare engineering students for this reality [1, 2]. This will be accomplished only if knowledge becomes operative [3]. For this to happen students must work with knowledge so that it becomes meaningful. Therefore, learning should be directed to the development of competences that will improve professional performance [4]. Even though this concern is somewhat present in senior years, it is not common in introductory and basic courses, where the main concern is usually to cover the subject matter as stated in the syllabus [5, 6] and provide enough information for the students to carry on.

Reviewing the state of the art in educational research, the need for active learning [2, 5, 7–9] in promoting student participation and responsibility stands out. There are several efficiency factors in Science Education Research and in Engineering Education Research, involving permanent interaction among students and between students and teachers [8, 10–16], and pointing to the importance of mobilizing students' prior knowledge in order to construct more solidity [17]. All this can be accomplished in the classroom using collaborative learning [18, 19], cooperative learning [20], project work [21–23], tasks to be performed by the students [9, 24, 25] associated with permanent and adequate mediation by the teacher, between students, involving their prior knowledge and physics knowledge connected to the real world of engineering [9, 26].

We define mediation as the integrated actions performed by the teacher to facilitate students' learning [27]. In association with the usual concerns of teaching, such as preparation of the curricular materials, types of approach or evaluation of students' progression, mediation of students learning also concerns the way teachers can develop students' knowledge and competences in the classroom. This concept will be developed in Section 2.

The Bologna Process perspective [28, 29] of making students active in their daily classroom activities and in improving their responsibility for and capability to do autonomous work, must first be acknowledged by the teachers. This means that teachers have to be prepared to perform an efficient mediation closer to the students. It is common to find teachers who are careful in the preparation of the materials, give informative lectures and obtain good evaluations from their students. But, by doing all the hard work (probably to prove to the students how easy it can be), teachers are not really helping their students in their construction of scientific knowledge. So, even

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if students think they understand concepts clearly, later on they will have difficulties in applying them in different situations [5, 7, 30]. This means that teachers should try shifting this responsibility to students, so they can build their own mental models [31]. That is why involving students and mobilizing students' prior knowledge from the beginning is one of the most important of a teacher's tasks. This work makes explicit how a teacher can mediate the student learning in the case of an introductory physics course in a polytechnic engineering school in Portugal (ISEP—Higher Institute of Engineering of Porto) and identifies some critical aspects of this teacher mediation.

Therefore, this paper is not so much about active learning methods, which are already established, but about the effects of the incremental implementation of teacher mediation, in and out of the classroom, from two perspectives: in an overall perspective over the four years and in a detailed perspective in the last year. It encompasses the design of teacher mediation and tasks for students and focuses on critical aspects of an effective teacher mediation of students' learning.

2. MEDIATION OF STUDENT LEARNING IN THE CLASSROOM

We use the expression 'mediation of student learning' (henceforth simply referred to as mediation) as the actions (verbal and non-verbal) of the teacher in order to try to develop systematically students' knowledge, competencies and attitudes to the levels demanded by the curriculum [27]. An example of teacher mediation consists in providing support for learners in complex tasks, 'that enable students to deal with more complex content and skill demands than they could otherwise handle' [26]. In a new, more challenging, learning environment where students are involved from the beginning, learning becomes dynamic and a fundamental role is what students develop and accomplish by themselves [2, 5, 9]. In this sense teacher mediation is one dimension of the teacher's work (in and out of classroom), but it is not only the act or process of imparting knowledge or skills to another person: it is the act or process of resolution of the students' learning demands based on the students epistemic work, in which the main roles of the teacher are scaffolding, questioning and engaging students.

The first step towards an efficient mediation is the preparation of the curriculum, in the sense of designing students' tasks and teacher mediation, to engage students in their learning work in and out of the classroom. The teacher's effort should allow the development and improvement of a student's knowledge, know-how and competences (taking as referent the curriculum intentions) without guiding a student's thoughts to the easy, straightforward option, so well known to the teacher.

The second step regards implementation in the classroom. The learning environment set up by the teacher has a crucial importance in the students' involvement and learning quality. Mediation can become more effective for most students if the teacher is able to empathize with them, providing an active social environment [2] where students feel comfortable presenting and discussing their ideas with each other [14]. Even though some students do not easily accept such a participative role in the classroom, teachers should gradually help them understand the benefits of becoming actively engaged. The expected results in the improvement of students' success and satisfaction is not usually immediate [10, 32]. The incitation to persist and to develop intrinsic motivation is an important part of the mediation conducted with students, as well as with staff colleagues (and the teacher).

To carry out a profound mediation, teachers must look upon students as an important part in the development of scientific knowledge in class and must consider their opinions, prior knowledge, questions or proposals as they try to embrace their interests during the lecture [33]. In order to make any class come alive, students must be an integrating part of what is being developed. The profits come from the interactive environment, with argumentation generated between students, during the attempt to construct their scientific knowledge [33, 34].

Several studies confirm the importance of making use of peer learning and teamwork [2, 7]. If students sense that the collaborative work developed during class with their peers is sufficiently motivating and profitable, they might continue this interactivity out of class spontaneously, by studying together, or simply discussing their doubts with each other, before resorting to the teacher. This engagement with one another will also be increased with team cooperative work [20], in which proper teacher mediation is crucial. While developing teamwork skills, students must understand their dependence on each other and develop important social competences such as respect and autonomy [20].

This motivation to do real work in class, in order to socially construct their knowledge and develop competences, can more easily be established by working upon scientific and technological contexts familiar to the students. If students understand the potential gains in learning and developing a particular subject, they might not only become more motivated, but establish more easily the necessary connections with the real world and their future profession. In this sense, the tasks proposed to students should be authentic [35], based on real and interesting contexts (adapted to the students) and should mobilize the students' prior knowledge.

It also becomes very important to make a quality assessment of the learning outcomes, on a regular basis. In order to ensure feasibility, these assessments must provide relevant results concerning the learning outcomes on the competences developed and concepts learnt [2]. Whatever the

kind of task performed (assignments, class questions, self-evaluation tests, etc), it is very important that students get proper and timely feedback on their learning outcomes. This feedback works both ways: teachers obtain relevant information about their students' learning evolution and students get useful (and timely) information about their own personal achievements. In doing so, assessment is no longer an instrument for measuring mistakes, but becomes a powerful tool of mediation, which can improve the learning process.

The mediation can be efficiently performed both in small and in large classes [10, 36], in laboratories as in lectures or recitation classes [7, 9], by mobilizing different dimensions of teacher mediation.

In brief, from the discussion throughout this section, we consider as fundamental the following dimensions of mediation:

(1) How teachers involve the students to work in the classroom. Student work depends on the type of support given by the teacher and the authority awarded to students [33]. In particular, the teacher may directly guide the students or, instead, structure and question their work [26].
(2) Scientific and technological contexts. This dimension concerns how the contexts and physical situations are taken into account, namely if problem solving is based on realistic contexts and if tasks are authentic [35].
(3) Assessment and feedback. Students and teachers need to get information about their developments and achievements, so they may act to correct any problems in time.

Our empirical study, described in Section 3, points out some critical issues about teacher mediation, not only regarding the establishment of the curriculum, but also focusing on the three dimensions referred above.

3. CASE STUDY: ISEP

This work is part of a curriculum redesign, based on research in physics education, which is being developed in an introductory physics course at a Portuguese polytechnic engineering school (ISEP—Higher Institute of Engineering of Porto). This curriculum had the goal of improving students' competences in their daily work with the physics subject matter and its connections with daily life, by using a diversified mediation in and out of class.

We believe that with this curriculum, with its strong emphasis on work developed by the students and on its feasibility, teachers were more likely to motivate their students to engaged in productive work and develop the desired competences. So, the redesign of the curriculum (in the sense of teaching sequences) incorporates a planned teaching mediation of student learning. Although teachers can actually improve their mediation just because of the nature of the tasks of the new curriculum, the individual teacher's perceptions of these tasks, their own experiences and personal interpretations of science education led to the differences found in the actual daily work in the classroom and the students' accompaniment after class. This translates in differences in the actual mediation performed. But how can a teacher improve mediation skills in order to improve students' achievements? In this case study, we collected and analysed data in order to illuminate a way towards obtaining answers in the following research questions:

(1) RQ1: What is the role of the incremental changes introduced in the curriculum (students' tasks and planned teacher mediation) in students' achievement?
(2) RQ2: What are the critical aspects of mediation of students' learning in and out classroom in the development of students' achievement and competences?

3.1 Description of the study

This work involves an analysis of the same course in four consecutive school years (always taught during the first semester of each school year—usually from September to December).

3.2 Curriculum design

The first year (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 research, namely those related to mediation. In 2006/2007 some of these changes were incorporated, and, additionally, were integrated with teacher mediation and students' tasks characteristics proposed by a formative situation framework—FSF [9]. So, in 2004/2005 and 2005/2006 we concentrated our attention on the design of students' tasks and teacher mediation traces based on the literature review. In 2006/2007, we also studied the effective teacher mediation in the three types of classes (T—theoretical, TP—recitation and Lab—laboratory), corresponding to the traditional teaching approaches: presenting the theoretical background (lecturing), solving paper and pencil exercises and doing experimental work, respectively.

Tables 1, 2 and 3 show schematically the development occurred in the course curriculum over the years, for each type of class.

A teacher-researcher and a group of teaching assistants (changed every year) implemented these students' tasks and teacher mediation design. Even though the teaching staff was completely in agreement with the goals of the new curriculum and regular meetings took place in order to establish equal standards, teachers actually performed different levels of mediation with their students

Table 1. Summary of modifications designed for teaching T (theoretical) classes

Dimension	**2003/04**	**2004/05**	**2005/06**	**2006/07**
Students' Tasks	Applications (end-of-chapter type problems after the exposition of the theoretical contents).	Discussion of some conceptual questions with their neighbours.	Peer instruction [6] during discussion upon conceptual questions.	Discussion of conceptual questions, first with their colleagues and only after with the teacher. 'Do and Correct' neighbour's test, during discussion of the solutions. E-learning Challenge: open-ended situation-problem, with open participation of all.
Teacher Mediation	Exposition on blackboard. Rhetoric questions. Prompt support during class. Normal office hours for student consultation.	Conceptual questions during exposition in projected transparency / blackboard. Prompt support during class. Normal office hours for student consultation.	Stimulate discussion upon conceptual questions, first between students and only then with the teacher. Exposition in PPT/ blackboard. Credit for participating in class. Prompt support during class. Normal office hours for student consultation.	Promote discussion between students with realistic situations and conceptual questions (before and after introducing a concept). Exploring animations and videos. Predict-Observe-Explain tasks[37]. Self-evaluation tests and discussion of the solutions, while students correct each other's test. Credit for participating in class. Prompt support during class.

Table 2. Summary of modifications designed for teaching TP (recitation) classes

Dimension	**2003/04**	**2004/05**	**2005/06**	**2006/07**
Synchronism with theoretical lessons	1 or 2 weeks delay.	1 or 2 weeks delay.	1 week delay.	No delay.
Students' Tasks	Individual work on the exercises. 2 or 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 exercises 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.	Teacher supervision of collaborative discussion. Prompt support during class. Support during the development of the Project. Weekly individual feedback on the e-learning homework. Office hours consultation suggested by the teacher to each student whenever deemed necessary.

and, in some cases, even modified the goal of some tasks.

From year to year, the type of problems proposed to the students in their daily work, as well as in assessment items, changed, becoming less dependent on their mathematical skills and more contextualized and focused on using their competences. The goal was to make students realize what they needed to know in order to solve any specific problem, figure out what was at stake and try to work out the solution themselves. Here, the important mediation is not only to devise adequate tasks and problems, which can help accomplish such learning, but also in providing teaching moments only when students have the need for such interventions. The questions given in final examinations

Table 3. Summary of modifications designed for teaching Lab (laboratory) classes

Dimension	2003/04	2004/05	2005/06	2006/07
Synchronism with theoretical lessons	No Synchronism	No Synchronism	No Synchronism	Synchronism with the theme (chapter) being discussed in the theoretical lessons.
Students' Tasks	Teamwork in class, based on guided experiments. Team Report. One final test on errors and uncertainties in measurements.	Teamwork in class, based on guided experiences. Self-preparation for the experiment. Team Report.	Teamwork in class, based on guided experiences. Self- preparation for the experiment. Team Report. Final autonomous laboratory work.	Autonomous collaborative teamwork in solving the laboratory problems, which require preparation. Final Project work.
Teacher Mediation	Expositive lecture about uncertainties. Exercises. Prompt support during laboratory. Feedback on the reports' marks. Normal office hours for student consultation.	Expositive lecture about uncertainties. Exercises. Individual questions about students work in laboratory and experiences performed. Prompt support during laboratory. Feedback on the lab reports. Normal office hours for student consultation.	Collaborative discussion with the teacher supervision. Individual and team questions about their work in laboratory and experiences performed. Prompt support during class. Weekly feedback on the lab reports. Final Project supervision. Office consultation suggested by the teacher to each student whenever deemed necessary.	

Table 4. Examination question example

2003/04	**Practical question (3.5 points in 20):** A particle vibrates in a simple harmonic motion with the frequency of 100 Hz 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	**Practical question (3.0 points in 20):** A particle is suspended from the ceiling of an elevator through a spring and is at rest relatively to it when the lift descends with a constant velocity of 1.5 m/s. Then, the lift suddenly stops, 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 particles' oscillation? (b) Which will be the motion equation of the particle? (Choose the positive axis up)

also underwent considerable modifications, in order to accompany and be aligned with the new curriculum goals [38]. This evolution is exemplified in Table 4, by a question on the same topic, but having a more contextualized background and testing different levels of understanding.

The structure of the final exam also changed. Traditionally the exam was divided in two parts: one theoretical (based on mathematical demonstrations) and the other with application exercises (similar to textbook end of chapter exercises), with a global minimum grade requirement of 8 points in 20; in 2006/07 we proposed an exam divided in 3 parts: theoretical (conceptual questions and deep-understanding questions), practical (with four problems and exercises, some of them orientated to assess students' competences), with separated minimum grade requirements and a laboratorial question. We intended to point out very clearly to the students that we were interested in getting them to engage in the course as a unit and develop competences in trying to solve more complex problems or applications related to real situations, not just in learning some of the concepts or how to solve some very specific problems [39].

3.3 Curriculum implementation

Now we describe what was done in 2006/2007 in each type of class in more detail. Different teachers (enumerated from 1 to 7, as indicated in Table 5), taught these classes, applied the same curriculum and worked with the same tasks with their students. However, the mediation used to accomplish those tasks was different, and in some cases, significantly different, as reported by the teachers in the end of the semester.

Table 5. Classes: distribution of teachers in 2006/07 (each number represents a teacher)

Classes/sections (number of students)	**A** (16)	**B** (14)	**C** (14)	**D** (15)	**E** (13)	**F** (15)	**G** (21)	**H** (17)	**I** (13)	**J** (8)	**K** (17)	**L** (17)	**N** (19)	**V** (19)
LAB	2	3	1	3	2	1	4	5	4	5	2	5	7	2
TP	1		4		3		1		2		6		6	
T	1						1				1			

3.4 Theoretical class (T)

Continuing the peer-instruction [7] and other active learning engagement strategies, already tested in previous years, the major concern was to establish class rhythm, in order to maintain students' attention. The teacher would present an initial conceptual question about a specific subject, and through discussions and conclusions reached by students, infer their possible prior knowledge. If difficulties and misconceptions appeared, the teacher would try to overcome them (using some materials prepared in advance for such possibility). Then some expositive lecture would occur, with conceptual questions, realistic situations or contextualized examples also being presented, always stimulating peer learning and the participation of all students.

The major innovation introduced was the short self-tests performed in class and their immediate correction by each student's neighbour, while the discussion of the solutions took place.

The e-learning challenges provided an opportunity for students to work together in complex problems, in which everyone could see each other's point of view, and complete or disagree with them. The teachers would supervise students' interactivity and give clues whenever they felt was appropriate.

3.5 Theoretical-practical class (TP)

In general terms, the curriculum implementation occurred as indicated on table II. However, the teachers involved in these classes (see table 5) performed different mediations.

3.6 Laboratory class (LAB)

The major modification was the almost total abolition of guided experiments. We opted for simpler laboratory devices, which could demonstrate simple concepts that were being developed in the theoretical classes. This allowed all students to work on the same topic (not necessarily the same experiments) at the same time. The final part of the semester was spent developing a laboratory project, intended to solve a specific problem, in which students with the available material should idealize, develop and implement an experiment that could test the answer to that problem [40]. In these classes the students of each TP class (Table 5) were divided in two groups, with approximately 15 students each.

The distribution of teachers by classes (imposed by the institution, not a research arrangement) is presented in Table 5. Teacher 1 is the only one that remained on the teaching team during the four years.

3.7 Data collecting

The instruments used to collect data about teaching were:

- the curriculum materials;
- informal conversations or meetings about teachers' perspectives on curriculum implementation;
- the e-learning challenges and information about the mediation performed by teachers;
- audio recordings of classes taught by teacher 1;
- interviews with teachers, asking questions about six aspects of their work in class:
  (i) how the class work was organized;
  (ii) how the tasks were presented to students;
  (iii) what were the students' role in accomplishing those tasks;
  (iv) how was the collaborative discussion conducted with teacher supervision;
  (v) which support was given during class;
  (vi) which support was given during the development of the project;
- interviews with teachers asking questions about five aspects of their work out of class:
  (i) frequency and students' coverage of the weekly feedback on the e-learning homework;
  (ii) what kind of feedback was given;
  (iii) teacher participation in the open discussions in the e-learning platform;
  (iv) office consultations suggested by the teacher to each student;
  (v) students' attendance at the regular office hours.

The instruments used to collect data about learning were:

- informal remarks that students made to teachers;
- an anonymous questionnaire to students at the end of the course, the QEAME (a questionnaire about teaching, assessment and studying used by [22] and partially based on [41]), with several questions about students' perceptions about classes (see Appendix 1), namely in each of the following dimensions: deliberated effort towards good teaching, permanent evaluation, permanent interaction and stimulus to the student independence;
- competences test (an example is shown in Table 4, last question);
- the e-learning tasks and challenges;

Table 6. Students taking the course until the end and their final results

Dimension	2003/04	2004/05	2005/06	2006/07
Total number of students who tried to complete the course	*141*	*146*	*166*	*169*
Failed the course (took the final exam but gave up)	2.1%	1.4%	1.8%	0.0%
Failed the course (reached a pass mark, but still failed the course because they did not reach the minimum mark in one or more of the course components)	8.5%	7.5%	9.0%	12.4%
Failed the course (did not reached a pass mark)	36.9%	26.0%	34.9%	21.9%
Passed the course	**52.5%**	**65.1%**	**54.2%**	**65.7%**

- interviews with students focusing on their perceptions on particular aspects of the curriculum, how they were implemented by the teacher in each type of class and their opinion on how they contribute, or not, to improve student learning. These interviews were performed after the course was finished, during the following semester, and some of the students were able to make comparisons with other experiences of teaching and learning.

4. RESULTS

We present the results to answer the two research questions:

(1) What is the role of the incremental changes introduced in the curriculum (students' tasks and planned teacher mediation) in students' achievement?
(2) What are the critical aspects of mediation of student learning in and out classroom in the development of students' achievement and competences?

4.1 The role of student's tasks and planned teacher mediation in students' achievement

To answer this question we performed a global analysis over the years to find the evolution of students' results.

In order to globally understand the consequences of these teaching interventions we compare the four years, starting by characterizing the number of students who took the course and the percentages by final outcome (Table 6).

Considering the students who have tried to complete the course and were, therefore, submitted to assessment it is clear that the numerical grades have improved, specially in this last year, as shown in Fig. 1 by the final numerical grade distributions (in a 0 to 20 scale).

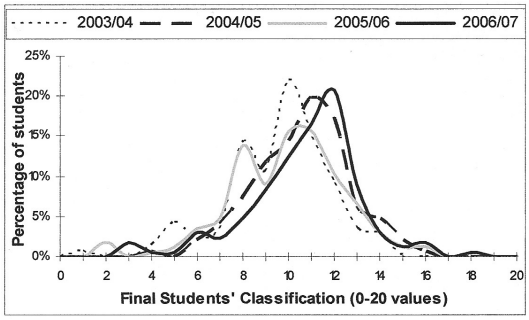

Fig. 1. Final results distributions throughout the four school years.

At the end of the course, students answered the anonymous questionnaire (QEAME) in the e-learning platform. We compared the results (36 responses) with those obtained in the previous year (33 responses). These are the averages calculated for the answers in each dimension shown in Table 7 (each dimension included 3 or 4 questions). This table shows an improvement in all the dimensions significant to this study.

The last three indicators of Table 7 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.

Even though few students answered the questionnaire, we believe the pattern of students who complete it (in both years analysed here) was similar, because the ratio between sample and population sizes was almost the same and these results are consistent with data obtained from the students' interviews.

In the interviews of both teachers and students, it became clear that students appreciate solving the problems by themselves and resent when they feel that not enough time was given to do so, but (some) were uncomfortable with the amount of work performed in class, indicating that they would like an intermediate solution, with the teacher solving some problems, so they would gain more confidence and sense that they would leave the class with more work done. They felt the need to have the worked-out problems to study and prepare for the exam. Some of the teachers ended by doing just that, when they felt the students needed more help. Nevertheless, students and teachers, in general, indicate that motivation in class increased (comparing with their previous or other experiences) and the discussions in class

Table 7. Median results obtained about students' perceptions about classes (QEAME) (using a Likert scale of agreement, from 1 to 5)

Dimension	2005/06	2006/07
Deliberated effort towards good teaching	3.5	4.0
Permanent Evaluation	2.5	2.9
Permanent Interaction	3.0	3.4
Stimulus to student independence	2.3	2.7

were profitable and more or less participated in by everyone. Another fact pointed out by the teachers was the low attendance of students during their office hours or to the personalized meetings. Some students state that they primarily seek out a colleague to resolve regular difficulties, and resort to the teacher only if this first resource failed. This effect is reported in the literature [42], but it may have been increased by the social competences developed in classroom and the permanent discussion the students engaged in with each other.

In the laboratory classes, the synchronism among the topics (complementing the theoretical approach with practical and experimental work) seems to be helpful in achieving the goal of helping students to connect the experimental procedures with the concepts being developed in the course. Most of the students interviewed did realize it and regard it as a positive aspect. In this case, the small differences between the mediation performed by different teachers all led to positive results, with the majority of students carrying through their final laboratory project successfully, revealing developments in both subject specific and social competences. Even the weaker students revealed themselves positively in this final project, as was stated by more than one teacher.

These results show that, as we gradually improved the design of students' tasks and mediation traces from year to year (as summarized in Tables 1, 2 and 3), so did the students' grades. Student perceptions show that they recognize the efforts made by teachers and the improvements in the curriculum, namely in terms of teacher mediation and of their own learning. So, it is reasonable to attribute the improvement in students' achievement to the curriculum developments progressively implemented.

4.2 Characteristics of teachers' mediation

We make a preliminary analysis of the differences among teachers, using as criteria the items shown in Tables 1, 2 and 3. From this preliminary analysis we found that in the Lab classes the mediation of the different teachers had no substantial differences. But in the TP classes we found remarkable differences among teachers' mediation, including different interpretations of the intended curriculum. Even though the teaching staff was completely in agreement with the goals of the new curriculum and regular meetings took place in order to establish equal standards, teachers actually performed different levels of mediation with their students and, in some cases, even modified the goal of some tasks. In particular, the mediation used to accomplish those tasks was different, and in some cases, significantly different, as reported by the teachers in the end of the semester.

We carefully analyse teachers' mediation in the TP classes using the three mediation dimensions presented in Section 2. Each dimension is analysed with operational questions. The analysis results are presented for each dimension.

4.3 Mediation differences among teachers in dimension 1: "How teachers involve students to work in the classroom"

The results concerning this dimension are presented in Table 8.

The project tasks present in the curriculum were primarily idealized to involve students in inquiry and discussion with their colleagues and enrich their understanding based on their prior knowledge, while working on real problems.

Even though the same tasks were given to all students, the way they were presented to them led to different engagement in their accomplishment, leading to substantially different individual learning outcomes in most of the students.

It becomes clear that the mediation performed by teacher 6 was based on information transmission with only some moments of interaction. In that way, most of the tasks became exemplar routines, since the teacher would explain how they could be solved. This teacher confirmed that he did not give enough time for the peer discussion and that the complete solution was shown before most students were able to accomplish it themselves. The information flowed from teacher to students.

Teacher 3 did not stimulate much collaboration in class between students and preferred to interact with the entire class, where only a few participated. The brainstorm performed in some problems by this teacher could be the most reflective and enrichment moment for the students (even though certainly not all of them). The information flowed essentially from teacher to students.

With teacher 4, even though working collaboratively in classroom, students would only engage in real work after the problem was dissected before them with the help of the teacher, since the students' thoughts were being closely guided by the teacher. Students would not have the opportunity to overcome the difficulties they were bound to discover if they were working autonomously. At a first glance, this may be seen as profitable to some students, since it produces a greater amount of work in the same period of time, but most likely this knowledge does not became operative. The few students who really participated in the debate with the teacher, who profited from the discussions and thoughts of others, would be able to reconstruct knowledge and develop competences by interpreting and/or interacting with others' thoughts. It does not seem probable that this happened for most students, because they had no time to think things through, before the solution (usually developed by only a few students) came out. For the major part of students the information flowed from teacher to students.

This kind of mediation was also performed by teacher 2, since only the objectives of problems were discussed. This would allow students to get help in interpreting the problems, but not in the ways they could solve them. Teacher 1 tried to establish real cooperation between students and

Table 8. Differences in mediation implemented in classroom among teachers of TP classes, related to Dimension 1

Analysis categories	Teacher 1	Teacher 2	Teacher 3	Teacher 4	Teacher 6
How is the class work organized?	Students worked in their project teams of 4–5 students, by turning to face each other.	Students worked in teams of 4–5 (not necessarily coincident with their project team), by turning to face each other.	Students worked individually or with their next seat colleague, in a traditional school table's distribution. Only in the project (in the end of class) they would join with their team.	Students worked in teams of 4–5, by turning to face each other.	Students worked individually or with the colleague in the next seat, in a traditional school table's distribution.
How are the tasks presented to students?	Project tasks were developed in the beginning of the class. Once finished, they would move on to the problems and exercises previously distributed.	Usually they would begin with the project tasks, but when there was less time, the teacher would ask students to initiate with the problems. The teacher discussed the objectives of each problem out loud and then they would try to solve it on their own.	In the first few problems the teacher worked them out in the blackboard with the students' collaboration; Brainstorm in some exercises.	Before initiating each task or problem, the teacher would ask some questions to class, in order to establish a way towards the solution, and then they would end it by themselves.	Teacher gave a few minutes for students to solve each task or problem, and then asked for their contributions before presenting the solution in a projected transparency.
What is the students' role in accomplishing those tasks?	Autonomous role, with no synchronism among teams.	In most problems, only a few students participate in the discussion.	In most problems, only a few students participate in the discussion.	In most problems, only a few students participate in the discussion.	In most problems, only a few students participate in the discussion.
How is the collaborative discussion conducted with the teacher's supervision?	Most of the teams engaged in real collaboration with each other, performing peer-learning.	Most of the time there was no team autonomy. Some teams performed peer-learning.	Little engagement in class.	Most of the time there was no team autonomy and most teams clearly evidenced a leader, who would explain to their colleagues, but they were not very motivated to do team work.	Little or none.
Which support is given during class?	The teacher would visit each group several times in each class. Prompt support (not the solution, but clues instead) was given to each team in crucial times.	Sometimes the exercises were solved by the teacher in the blackboard whenever the teacher sensed difficulties from most students.	Nearly half of the problems (the first ones) were developed on the blackboard by the teacher.	Most of the times in the blackboard; rarely in each team. The teacher would explain students' doubts out loud to the entire class, most of the times.	After a while the teacher gave the solution in a projected transparency.
Which support is given during the development of the Project?	During class. Feedback on their partial intermediate goals.	During class. Many students did not meet deadlines.	During class. Feedback on their partial intermediate goals.	During class. Many students did not meet deadlines.	During class.

force them to think and go through their natural difficulties in order to evolve and develop competences. The fact that as soon as students realized that no problem was going to be solved for them on the blackboard, they realized the necessity of trying it out in order to call the teacher for help, because they knew they would have to present some work done in order to get some kind of clue or help. Most times, this teacher awarded authority to students, because they controlled their own learning and enriched themselves by discussing, listening to each other and constructing the solutions together. The information flowed among teacher and students.

4.4 Mediation differences among teachers in dimension 2: "scientific and technological contexts"

Despite the proposed tasks being generally descriptive problems in context, the way they were presented to students and operated by teachers in the classroom was different. All

teachers, depending on their point of view and what they thought was most important, put more emphasis on different things.

Even though this dimension is more difficult to analyse without being in the classroom, it already became clear, from analysis of the previous dimension, that the approaches on the contextualized problems were different, mainly in making the problem tasks into authentic tasks to the students. We found out that some teachers thought their important role was to give students' examples of very well organized solutions to some problems, regardless of their contextualization. Others thought the importance of their work was to make students see the connection between what they were trying to develop and the real world.

For example, a particular problem in these classes was a situation involving a car suddenly braking at a red light. There was information about the initial velocity, the time it took to be immobilized, and students were asked what would be the force upon the passenger. By informal conversations, it became obvious that different perspectives were worked out. All teachers tried to make the best of it and explore what, in their mind, was more important for students to learn: some teachers asked the students to analyse what was at stake in this real situation and made students think about the differences in having a larger acceleration or a smaller mass, for instance, in the case of a child. Others automatically translated the situation through an abstract scheme and mathematically solved the situation, without further reference to the realistic implications.

4.5 Mediation differences among teachers in dimension 3: "Assessment and feedback"

Even if an efficient mediation is being performed in class, in order to keep up student engagement, especially if there is no cooperative interaction (such as project work, for instance), which might spark their interest, the assessment and feedback becomes very important. There are several ways in which this might be performed. We used e-mail, an e-learning platform and office hours. Sensing that the teacher knows and is worried about students' learning, students might tend to commit themselves in performing well. This kind of feedback on their homework (or other task) should be helpful in order to overcome some difficulties, but should not provide the entire solution to the problem or task. As stated before, teachers must help students in their construction of scientific knowledge, not replace them in that process. So, we carefully analyse the teacher assessment and feedback given to students for each TP teacher, using predefined categories, as summarized in Table 9.

The assessment and feedback of teacher 1 is performed on time, is personal and induces learning by engaging students in performing tasks by themselves. Most teachers did not realize it that way or, for some reason, could not deliver it on time.

Table 9. Differences in assessment and feedback implemented among teachers of TP classes

Analysis categories	Teacher 1	Teacher 2	Teacher 3	Teacher 4	Teacher 6
What is assessed during class	Students' participation in group discussions. Project tasks development.	Students' participation in group discussions. Project tasks development.	Students' participation in class. Project tasks development.	Students' participation in group discussions. Project tasks development.	Participation in class.
What is assessed after class	Weekly task in the e-learning platform.	Weekly task in the e- learning platform.	Weekly task in the e- learning platform.	Weekly task in the e-learning platform.	Weekly task in the e- learning platform.
Kind of feedback	Clues for completing task, call for attention on major mistakes, stimulus.	Right or wrong.	Right or wrong, occasionally the solution was given.	Individual corrections were delivered to each student.	The solution was given.
Weekly feedback on the e-learning homework.	Always, before next class.	Only to the few who did it on time.	Only to the few who did it on time, to the others, only if they ask the teacher.	Not always.	No, the teacher made a short survey of common mistakes in classroom.
Participation in the open discussions in the e-learning	Regularly.	Never.	Once.	Never.	Never.
Office consultation suggested by the teacher to each student.	Suggested every time teacher found it necessary.	Sometimes, when necessary.	Sometimes, when necessary.	Sometimes, when necessary.	No.
Regular office hours	Not all students took advantage of it.	Few students took advantage.	Few students took advantage.	Few students took advantage.	Rarely.

4.6 Critical aspects of mediation of student learning in the development of students' achievement and competences

This additional analysis enables us to identify some critical aspects of the mediation performed by teacher 1, which seem to make a positive difference compared with the other teachers in order to promote active engagement of the students. We present these aspects in Table 10.

The mediation performed proves to be positive, as perceived by the teacher and students: most of the students who attended the classes were involved and participated in the peer discussions promoted; all interviewed students stated that these moments were very helpful in their development and some of them point to them as the most helpful part of the course. This mediation took into consideration students' achievements and difficulties, considered in the literature as helpful to students [7, 14, 43] particularly in building their own knowledge in a more meaningful way [3, 9].

4.7 Analysis on students' performance and competences in TP classes, in 2006/07

We can see in Fig. 2 that GH class (taught by teacher 1) has the best pass rate. This might be

Table 10. Critical aspects of mediation performed by teacher 1, in and out of classroom

Action	Main Objectives	Dimensions of Mediation Involved
Keep the tasks as real problem until students find a solution.	Stimulate students' engagement. Facilitates the connection to the real world.	1, 2
Develop a social learning environment in class, inciting to team work and their cooperative engagement as groups.	Develop social competences, autonomy and responsibility.	1, 2
Diversify assessment and award participation in the different activities.	Develop and assess different kinds of competences. Stimulate everyone to participate.	1, 3
Provide homework and tasks that are simultaneously challenging and demanding, but not excessively difficult.	Allows students to individually test their learning outcomes.	3
Promote open-problem discussions in the e-learning platform.	Allows students to think upon others opinions Gives the teachers a more complete view on how students think.	1, 3
Promote peer-learning discussions in class.	Make a class alive and promote the participation of all students. Identify learning outcomes. Manage the curriculum.	1
Promote regular self-evaluation tests and their correction by other students.	Make students aware of their difficulties in time (they could also gain sensibility to common mistakes they usually make, but to which they do not pay enough attention). Make teachers aware of students' difficulties in time.	3
Alternate between necessary moments of expositive lecture with engagements tasks (which should be as varied as possible).	Keep up students' motivation and attention in class. Contextualize and/or calls on students' attention the pertinence of the next subject. Provide the teacher with immediate feedback on the students' learning.	1
Resist the (natural) impulse of explaining everything, every time a student has a question, but give clues instead, in order to let the students reach their own solutions.	Provides the development of competences and the students' re-construction of their knowledge. Force students to think instead of being just listeners.	1
Provide for help, guidance and explanations only in crucial moments.	Allow students to overcome natural difficulties (stimulus to autonomy; supervise team discussions). Allow students to perceive the pertinence of the new knowledge.	1, 3
Provide for regular, relevant and in time individual feedback of students' outcomes.	Allows students to evolve in their solution, rather than just realize if they are right or wrong (in the cases of serious difficulties, students were called to specific office meeting). Allows teachers to realize the real difficulties students feel.	3
Provide and stimulate easy access to e-mail, office hours and after class attendance (out class).	Allows students to freely pose questions they were not able to ask in class.	3
Discuss realistic situations.	Facilitates the connection to the real world. Clarify the concepts.	2

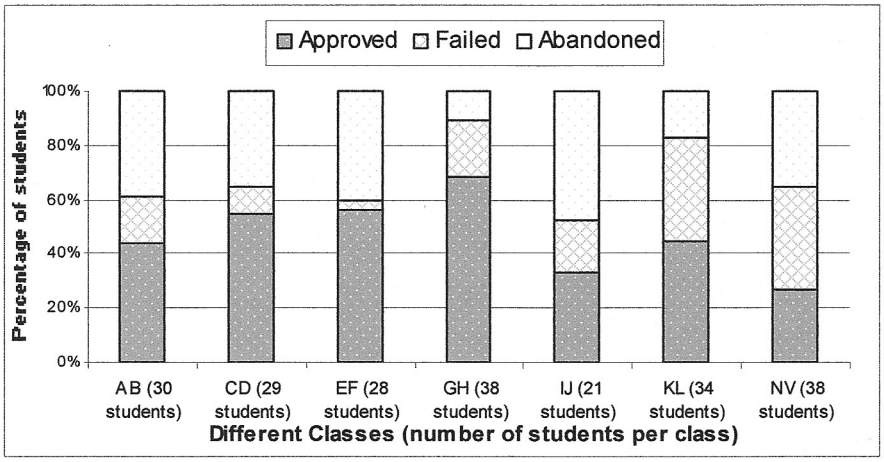

Fig. 2. Course results distribution.

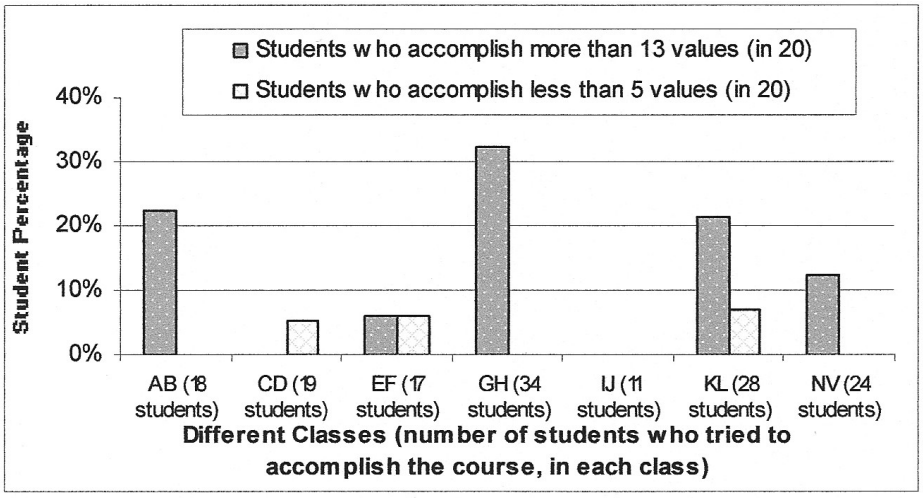

Fig. 3. Higher and lower grades comparison (in a 0 to 20 scale).

related to the fact that these students received constant feedback on their learning outcomes (always in the TP classes and almost every time in the laboratory classes). Feeling this attention from the teacher, students might feel motivated to work harder, as some of them state in their interviews. This may also explain the lower percentage of students who abandoned the course. In AB class (also teacher 1) this is not so clear because the majority of these students was repeating this course and had less time to accomplish the weekly tasks presented (repeating courses increases total weekly hours and may produce some schedule incompatibilities, namely in the attendance of the theoretical classes).

We also evaluated the number of students in each class that achieved more than 13 (in a 0–20 scale we consider this a good result) and those who did not achieved more than 5 (see Fig. 3). In this comparison, students in classes AB and GH clearly performed better.

Figure 4 shows the results of a detailed analysis of the competences test performed by the students. This test, in particular the question analysed (last question in Table 4), involved the competences to interpret, establish relations and deduct consequences in a realistic 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 that students still feel with this type of question. Nevertheless, the best result is obtained in GH class.

As we explained above, the mediation performed by teacher 1 is very different from that of other teachers. Teacher 1 devolves to students the responsibility to learn and helps them to accomplish this aim. Even with the competence test limitations (only one question), the results show that it is in the classes taught by teacher 1 that the competence to face and solve a problem posing a realistic situation is better developed. Besides, it is in those same classes that the students' achievement improvements are more important and extensive with the majority of students.

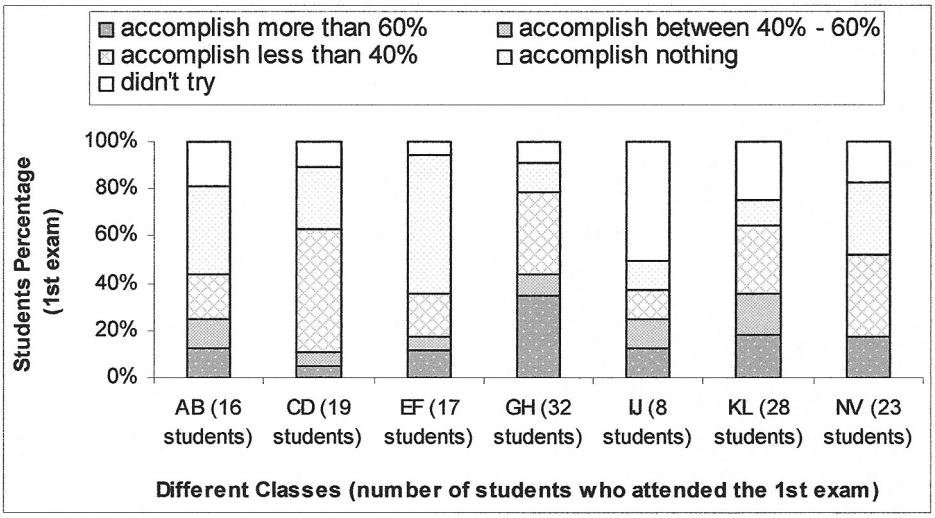

Fig. 4. Distribution of results obtained in a competence question.

5. DISCUSSION

The academic results point clearly to an increase of success in the course from year to year, as measured by most students' final marks. The results, generally considered, show that the efforts contributing to a more effective teaching produce progressively better academic results (pass rates). This result is consistent with that of others who report implementation of small improvements in the curriculum with benefits for students [2, 16, 22, 25, 42]. We have reported here a case study lasting four years and involving several teachers; our innovation consists in articulating tasks and planned mediation iteratively, in a coherent and feasible curriculum design. These two singularities may show that, even in unfavourable circumstances, if alignment between course aims and students' needs is tried consistently and in a gradual way, the students recognize the effort and their achievement improves.

Even though students recognized the learning environment and described it favourably, we felt some resistance in some of them to adapt to these active learning methods, in which the amount of student work is increased. On the other hand, some students revealed an enhancement in their motivation, developing important competences in cooperative work and reported that the regular assignments and teachers' feedback was important to overcome some difficulties during the course.

It became clear that the mediation performed by different teachers in implementing the same curriculum aims, regarding the real work students performed in class, the contextualization and the feedback delivered on the assessments, was different. The best results, in particular in competences development, are obtained in those classes where the learning environment was based on autonomous real work, solving realistic and complex problems and where teacher mediation was diversified and centred on students' work and accomplishments. In these classes:

(1) The academic results were equal or even better than in classes taught by a more traditional approach;
(2) High level competences were better developed in a larger number of students than in those classes taught by a more traditional approach.

The differences found in the mediation performed by different teachers were most significant in TP classes. This might be due to several factors, but we believe that in the laboratory classes, the curricular modifications were better understood and more easily performed by every teacher, since the philosophy of the laboratories began to change two years before, in 2004/05, with the implementation of students' autonomy in these classes.

In TP classes, most teachers failed to understand the importance of letting the students work out the problems and, in their goodwill, tried to inflict their thoughts on students, depriving most of them of the opportunity to think for themselves. The differences in teacher mediation revealed that the development of student competences is more likely to be achieved if teachers pay particular attention to how the students work in the classroom and its contextualization, and to how the assessment and feedback are performed. Therefore, student learning quality is enhanced if:

(1) teachers structure and question student work, instead of directly guide the students;
(2) information flows among the participants (students and teachers), instead of being unidirectional from teacher to students;
(3) the assessment is diversified and feedback about student learning is timely. If this feedback is not given on time, or not at all, students fail to see the advantages and tend to abandon the tasks where they have more difficulties.

6. CONCLUSIONS

The discussion above provides us with answers to our research questions. First, the incremental changes in the curriculum, in the design of student tasks and teacher mediation, which improved, in general terms, student performance. The role of mediation in student achievements was important for gradually increasing interaction in the classroom (in all types of classes) and the number of open-ended tasks that were developed based on practice and experience gained. This experience was also important to improve teachers' mediation design from year to year, given that curriculum design must incorporate a plan for teacher mediation. The redesigned curriculum is intended to develop new knowledge based upon realistic problems and invoking the students' prior knowledge, where knowledge is seen as something in construction or as an open field. The results point to an improvement of students' grades and satisfaction.

However, all this was insufficient on its own to develop competences in the majority of students, particularly weaker students. To help accomplish that, effective teacher mediation plays a major role.

Secondly, our results point to the fact that teachers need more than their scientific expertise in order to be able to engage students in real and profitable work. However, enriched teacher mediation is feasible and it can be improved and diversified. The most enriched teacher mediation in our study is characterized by improving students' epistemic work through teacher feedback, questioning and scaffolding. In this way the teacher avoids doing what the students can do with a certain kind of support. This is important for feasible high quality teaching.

The fact that teacher 1 was the only teacher who had the opportunity to improve mediation by small increments in quality from year to year, leads us to believe that mediation quality and feasibility is due to incremental evolution during the last four years, in which teacher competences in mediation improved, based upon reflective action and the teacher's past experience.

In summary, our results show that students do achieve better results and a higher level of competences when the teacher implements a curriculum with proper mediation, in and out of classroom, by engaging students with real work in class, mostly collaborative work, and motivating them to continue the work out of class.

This paper identified some critical aspects of an effective mediation for the development of student competences:

- how the student work occurs in the classroom, in particular the support given by the teacher, who should structure and question work, without directly guiding it, therefore affording progressive autonomy to the students;
- the scientific and technological contexts and how physical situations are taken into account, so that students truly engage in problem solving in real-life contexts;
- assessment and feedback, involving students in continuous work and providing for the necessary and timely feedback on their developments.

This work is part of a larger research project to improve teacher mediation in classrooms. In the future we intend to focus our attention on how to develop specific types of epistemic work important for engineering students.

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APPENDIX

Part of QEAME questions concerning this study

Dimensions	Questions
Deliberated effort towards good teaching	(18) Our teachers are extremely good at explaining the teaching subjects? (20) Teachers work hard in making this course attractive to students? (26) This discipline tries to really get the best from all students?
Permanent Evaluation	(7) The teachers of this course devoted enough time to comment on student work? (8)* To pass this course all you really need is to have a good memory? (12)* The teachers of this subject seem more interested in testing what we have memorized than what we understand? (21)* Teachers place students with too many questions that relate only to the facts? (22)* Information on the work of each student is provided ONLY in the form of ratings and notes? (25)* You can pass this course by working hard just on the eve of the examination? (27)* In this course there is little choice in the ways we are assessed?
Permanent interaction	(3) The teachers of this course motivate students to give their best? (5)* The teachers of this course often give the impression of not having anything to learn from students? (15) Teachers make a real effort to understand the difficulties that students may have in their work? (17) The teachers of this discipline will usually give information about students as they progress? (23) We often discussed with our teachers about how we learn in this course? (24)* Teachers do not show real interest in what students have to say?
Stimulus to the students' independence	(2)* There are few opportunities to choose the particular topics you would like to study? (9) This course seems to encourage students to develop as much as possible, their own academic interests? (11) Students have a great chance to choose how they will learn in this course? (16) It is given enough choice to students in the work they have to perform?

Note: * question with inverted score.

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