Introductory Physics Teaching in Engineering Education: How Can the Reflection on Teaching Practice Be Used to Improve Teaching and Learning?

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Abstract — *The reflection upon the teacher's practice and its analysis as a research issue can be an influential mechanism to understand and overcome students' problems in learning. We focus the reflection on teaching practice on: i) the effectiveness of the designed teaching sequences supported on the practical specific problems encountered in the classroom; ii) the teacher's mediation of students learning and the way students engage in developing their learning and their competences, as planned in the curriculum. The research question we intend to answer is: how can the reflection upon the teachers' practice in the classroom help them modify the teaching sequences and the effective mediation with students in order to improve students' involvement and their learning?*

This study occurred during 4 years in an Engineering Polytechnic School in Portugal (ISEP) and involved the observation and self-evaluation of the implementation of an introductory physics active curriculum, its critique and correspondent modification decisions. The data collected included the teacher's reflections after class (identifying the teaching and learning problems and successes, possible causes, as well as ways of overcome or explore them even further in the future), students' perceptions about teaching, classes and learning; students' academic results and developed competences; the modified curricular materials; and teacher multimodal narratives of some classroom episodes.

The analysis of the referred data, during the 4 years of implementation, allows us to enlighten some real problems of teaching and learning and led to improvement, iteratively, in the teaching practice and in the teacher professional development. The course curriculum, the design of learning tasks, the design of teachers' mediation and also the effective mediation of the teachers in the classroom, was successively improved. The conclusions are also supported by the improvement of students' competences and their final academic results. The teacher's multimodal narratives are a useful instrument of reflection about the effected mediation. It can be helpful for the teacher himself and for others, who might encounter the same kind of difficulties and constrains. This microanalysis can clarify some important aspects of student learning and help to understand how an effective teaching mediation, that is feasible in real context, may contribute to develop student learning.

Index Terms — *Engineering education, professional development, reflection on teaching practice, students learning, teaching practice, teaching physics, teacher's mediation.*

INTRODUCTION

Some studies show how the research on teaching has influenced the teaching and the teachers' perception [1-4] and encourages reflection and use of teachers' competency as a researcher in order to see the educational problems as problems of research [5].

Ramsden [6], in his identification of effectiveness factors for higher education, states the need for modifying teaching according to the evidences, thus referring to the reflection on practice and analysis of results. Perrenoud [7] considers "absolutely essential that teachers are able to go beyond the textbooks, invest in their disciplines, re-invent their evaluation skills, using their own research experience and their social practices knowledge". Other authors, in engineering contexts [8], also underline this need to evaluate teaching, using longitudinal studies to evaluate the proposed teaching methods, as well as their success.

Mason [9], in his book entitled "Researching your own practice", specifically advises teachers to be aware of particular details in class that may influence students' outcomes. As this author points out, they will be quickly forgotten if not recorded in someway. In order to produce this reflection, teachers should develop habits of recording these small episodes, shortly after class.

STUDY DESIGN

This work aims to help elucidate how the reflections of the teacher-researcher and his interaction with other teachers about their teaching practice, guided the modifications made to the curriculum and the practice itself in subsequent years,

in order to answer the underlying research question: "*how can the reflection about the teachers' practice in the classroom help them modify the teaching sequences and the effective mediation of student learning in order to improve their involvement and their learning?*".

This reflection on classroom practice has led to modifications in the design of tasks and teacher mediation, and explains how it can lead to the improvement of the quality of effective mediation in the classroom. These reflections were supported not only in self-perception but also on the comments of other teachers, students' perceptions, tasks and mediation design and the outcomes in terms of satisfaction (of teachers and students), and of knowledge and competences development.

This action - research design involves teachers in a cyclical process consisting of several stages: the first phase of strategic planning; secondly the implementation of this plan; third, the observation and evaluation (including self-evaluation) and finally, a critical reflection (and self-reflection) about the results, including making decisions for the next cycle [10]. The first stages were described in detail in another work [11]. This paper considers the final stage of this study, based on two perspectives: a macro/meso analysis, focused on curricular changes to the planned tasks and mediation, based on reflection on teaching practice; a micro-analysis which studies the mediation in action, based on the teaching practice effectively performed in the classroom.

TEACHERS' REFLECTION UPON THE INCREMENTAL CURRICULAR MODIFICATIONS, PLANNED TASKS AND TEACHERS' MEDIATION

This section clarifies in what extent the perception and teachers' reflection influenced some corrective measures taken in the designed tasks and mediation. Thus, it presents the history of these changes caused directly by such assumptions.

The analysed data consisted on teachers' and students' perceptions, obtained through interviews and questionnaires, students' academic results and curricular materials. These data was collected over six consecutive semesters, since 2004/05 through 2006/07 in the Oporto Polytechnic School of Engineering (ISEP, in Portuguese). Seven teachers were involved in this study, lecturing the same course, including the teacher-researcher who had the dual role of proposing the curricular modifications inspired in literature and accumulated experience, and the analysis of its results in order to act in the subsequent semester.

Reflection on the Incremental Modifications to the Curriculum

In the end of the first semestre, based on his practice as well as his colleagues', the teacher-researcher made a reflection and induced subsequent curricular modifications. One of these were the modifications regarding the weekly homework, which seemed to have put students and teachers throught an excessive amount of work (complained by both parts), so in the following semester it became fortnightly. Other modifications were intended to reinforce some strategies that were successful: the laboratory assessment, based on students preparation of the experiments, submitting themselves to some oral questions about it, in order to explain the experiment's objective and procedures. Another reinforment, which was stated by everyone as potentially productive, was the use of an e-learning platform to support the course and enhance students learning and involvement.

In the second year, based on a literature review and these reflections, the main focus were to modify the course evaluation, through formative assessment tasks in order to help students' learning and alert them (and their teachers) if something needed to be improved. Diversified tasks were implemented in different type of classes (laboratory, recitation and theoretical), as well as post class tasks, in the e-learning platform. In order to stimulate students to participate, some of these tasks were not graded, merely awarding credit for students' participation [12]. A system of collecting points through students participation in theoretical class and associated e-learning tasks was developed. These points could be added to the students final grade. Teachers agreed that this was a stimulating factor which contributed to more students' involvement in the course. At the end of the second year, the most important modifications to the curriculum were already tested and the first conclusions led us to believe that our results were in line with the literature [5, 12, 13]: the students' active role was not only finding their receptivity, but was also producing more consolidated learning.

So, in the last year, this was reinforced, introducing a project work and a stronger appeal to students' autonomy in class and correspondent responsibility for their learning.

Reflection on the Planned Design Review of Tasks and Mediation

- **Tasks and mediation in theoretical classes**: In these classes several conceptual questions [12] were given in order to involve students in classroom discussions. The teacher researcher made a lesson plan (guidelines indicating available questions or discussions that could be aroused in order to elucidate particular aspects of the subject matter) in which he then recorded which questions had provided productive discussions and those that did not (referring the problems found: too simple, too difficult, not clear, not interesting, etc.). Using these after class notes, the questions could then be improved in order to become more clear, raise a more productive discussion towards the outlined objectives, and find the most appropriate time for each one (a question tagged as simple after the subject has been

discussed could become a good question to arouse the pertinence of the following development in class, if presented at the beginning). Even though these changes could only take place in the following semester, if they were not recorded shortly after class, the details surely be forgotten.

- **Homework and its mediation**: This task took different shapes along the years in order to become more effective in helping students in their learning development [14]. First it was delivered on paper and students should present it in the following week. Its discussion in class only occurred a week or two weeks after this. This time delay was not productive since the students would no longer remember their doubts when this discussion was being performed. On the other hand, several students copied their work from colleagues. In order to minimize these effects, and turn this task into a real learning tool, the teachers' feedback was planned differently in the subsequent years: it was delivered to each student in class, discussing not the problem solution, but the work that was performed by each student. The time delay became shorter and the feedback more productive in order to help each student to evolve. The only problem was the time spent in class. So, this task passed through another modification: it was proposed and submitted directly in the e-learning platform with tight deadlines (for submission: until 24 h before next class; for teachers' feedback: those 24 h). Since the homework questions also became less dependent on mathematical calculations and more about competence and conceptual testing, the teachers' feedback could actually be more helpful in detecting students' difficulties. This and the fact that feedback was delivered on time facilitated the overcome of difficulties.
- **Project work and its mediation**: This task was received with a great deal of enthusiasm from the students. In the first year the project involved several goals (milestones) during the semester, in which they were asked to present their accomplishments. However, several students saw their final mark impaired because of these earlier assessments. So, in the following semesters these assessments were made, but no grade was awarded, the teacher would only give feedback so that students could improve their work and stay in line with the design goals. It was discovered that this kind of assessment is not enough for the majority of the students. Only a few were able to understand its benefits and used it in order to construct a more consolidated work. Our conclusion is in line with what was already been established in the literature: students only develop what they are being assess for [15], but with a more immediate consequences: the majority of students only commit to fulfill the tasks if they know they directly influence their grade, they do not have the intrinsic motivation to comprehend those learning developments in a longer term. It became clearer that the students who were impaired by their lower grades in the intermediate presentations in the first year, actually performed better because they received an earlier warning to improve. Although the teacher mediation could help develop this intrinsic motivation by clarifying these formative assessment objectives, a formal quantitative assessment proves more efficient to the majority of students.
- **Laboratory project work and its mediation**: This laboratory project work was designed to develop students' competences and consolidate knowledge by having them try to solve some experimental problem. In the first year it was implemented, teachers realized that students were much more able to perform autonomous work than they thought possible, but because the available material was not very diversified, students had limited choices. The reflection upon the outcomes of this project lead us to believe that this effort was very productive and so in the following semester students worked more autonomously during all the semester and deliver a more complete task at the end.

The results of these incremental modifications were already discussed and published [11] and the principal conclusions drawn were that the design of the students' tasks improved over the successive modifications and so did the students grades in general. The more active role of the students in every type of class also contributed to their motivation. On the other hand the analysis of the teacher mediation when trying to implement those modifications was also studied [16] and their results point to differences between teachers, namely the real work students were able to perform in class, the contextualization and the feedback delivered on the assessments. In the cases where the teacher mediation was more diversified and attentive at those aspects, students academic results were equal or better than the rest, and high level competences were better developed in a larger number of students. In this work we meant to explain how the teacher's reflections upon the success or failure of those modifications and implementations led to a more coherent curriculum.

REFLECTION UPON THE ACTUAL TEACHERS' MEDIATION

This section studies the actual teacher mediation that occurred in the theoretical lessons of two teachers, regarding the same course, same subject, and using the same class resources (PowerPoint slides and questions): teacher-A (teacher-researcher) and teacher-B (who did not participate in the incremental modifications made since 2004). The data about these two cases was collected in 2007/08. The main data analysed were multimodal narratives [17], students' perceptions and students' development of competences.

Mediation analysis based on Multimodal Narratives

According to the Lopes, *et al.*[17], the multimodal narrative is the class story, richer than a transcript because it combines what is said, discussed or explored, the way it is done, the resources used, the students' reactions and expressions, the

expressiveness of the teacher (tone of voice, relative position to the students) as well as its sensitivity to what happened in class, with no intention to justify his acts, but simply to describe what led him to take certain attitudes in particular moments. The multimodal narrative may have more than one episode and an episode can last more than one class. An episode refers to all the events around a complete task (from the moment it is presented until it is finished or the teacher decides to terminate it).

Thus, it represents a story that can give a more faithful picture of what happens in the classroom. The aim is to analyze the performed mediation under various aspects, to reflect upon it and perceive more easily some possibilities of its improvement.

In a multimodal narrative, the researcher must contextualize the episodes and explain all the environmental issues that might condition the outcomes [17]. The following example took place after the students already discussed energy, waves and basic notions of electricity. It refers to an excerpt of the second lesson about heat transfer and the students had already learnt about temperature, scales, dilatation and its consequences in the structures. These theoretical classes took place in a ten rows' amphitheatre (each with eight seats). The lessons were supported by a multimedia presentation, in which some discussion slides were included. The teacher used also a white board to assist with particular developments in class. The average number of actual students per class was between 25 and 30, but not always the same ones. Teacher-A audio recorded the classes and added his memory of the events when writing the narrative himself. Teacher-B told what happened to teacher-A, who then wrote the narratives, based on these descriptions. We present an example of narratives of lessons from both teachers, corresponding to similar lessons:

Teacher-A

Episode 2 (started at 18m: 08s of the 2nd heat transfer lesson)

"Since the subject of thermal transfer in buildings is a subject that captures students, I decided to start it by posing a question (which appeared on a slide) *in which ways can a building be heated or cooled?* asking them to discuss in groups and register their conclusions, because we would be making an overview of their ideas. They discuss it for 3 minutes. Even the back students (apparently more distracted) participated in it. After some minutes they begin to tell me what they had considered, as I wrote them on the white board, completing and modifying what was already written (this part lasted about 5 min). The final appearance of the board is showed at Figure 1.

Sun
Heaters, fireplace, air condition (heating/ cooling)
Rain, humidity, wind…
Windows (open or closed), blinds, curtains, double glazing, double window, color…
Walls, materials, isolation, roof (all the surroundings)
People and all living things in general…
Lighting and electric equipments in general
Porch

FIGURE 1
WHITEBOARD APPEARANCE AFTER THE STUDENTS CONTRIBUTIONS

I then ask them to compare with the aspects that existed two centuries ago, and gave one more minute for their discussion. The most common references were "*there was no air condition*", "*the walls were made of stone*", "*…and more voluminous…*" The discussing went on and it was being hard to make the closure moments. At last I asked them to only consider the structure of the building: *which factors most influences heat transfer?* After one more minute with collaborative discussing, I asked for the outcomes…Some students show me they already finished but the majority went on discussing. I now intended to be heard so we could finish the discussion (it had already passed 15 min since the beginning), so I raised my voice and made a CHHH! They understand and shut down. I repeated this last question we were trying to solve, and wait for their answers. A student refers to the fact that the house might not be close to the ground…she was trying to draw attention to the air chambers, I presumed. "*the materials…*" says again the same student; "*the color*", says another, to whom I asked: "*and why that influences it?*" Another student says it's because of the absorption. I reply: "*before thinking about the absorption?*" The same student now refers the reflection and says a joke regarding some Portuguese costumes on that matter. Everybody laughs. Then another student continues: "*where it is*"…I tried for him to complete his idea: "*and that has to do with what*?" But after a moment pause another student refers to the orientation. I agreed: "*Very important, we had not yet mentioned this aspect, we have to be carefully with our house orientation, especially with what aspect?*" A student rapidly answers "*the bedrooms…*" I smile and say "*that was not the answer I was expecting…I was thinking about the windows…*" They wave their heads, showing me they knew what I was referring to, so I continued: "*And more?...Climate*? I asked. "*The geographical zone*" says the same student that earlier had referred to the place. "*That is why I asked what did you meant when you said the place…*" I attached. And then continued,

"what do you think is easier to work upon: a mild climate or one with great thermal amplitude? "Why is that important? The same student implies that the temperature may stay more or less constant…It wasn't explicit, so I asked again: "*what do you mean by that? why is that important?...if I have a great temperature difference between the inside and outside, the flux of energy is going to be the same as if I have a small difference?*". "*Of course not*", all agreed. So I continued: "*This temperature difference is what potentiates the heat transfer!*". We took 20 min to get here, a little more than I expected due to the involvement of the students in the discussions.

I then gave a conceptual question (about what's necessary in order to heat transfer occur, with multiple choices), just to insure that we were in tune.

I also had a second question, more contextualized, in order for them to relate with their daily life, but it was already time to finish class, so I just read the question out loud "*Why do we feel different sensations in our feet, when we stand on the kitchen floor and on a floor made of wood?*" and asked them to reflect upon it until next class. I noticed that as they were packing their things, they were already discussing it." (45m: 00s)

Teacher-B

"This part of the course captured students' interest. Not only were they more attentive and participatory as they add personal comments and knowledge. Some students' response speed suggested a prior reflection to the discussions. Some spontaneous students often answer incorrectly, based on a common sense (not scientific ...) but these responses were usually used by me to dismantle some reasoning / misconceptions' pre-learning of physics. I also called attention to the differences in reasoning - the "before" and "after". My class was at this point a little late, so the discussions were made in "real time" with the whole class (or almost ...) advancing possible reasons for the heating / cooling of buildings spaces, all together. The indicated causes were: heating / cooling, windows, walls, people, equipment...

I gave more emphasis to the "structure" issues, and their responses were, overall, quite full. I recognize the failure to propose a group discussion may have left out some shy, sleepy or uninterested students... but in this subject and at that time of the semester, those students were already residual."

Teachers' Mediation Characterization

Even though the nature of the presented narratives is different (due to the different elements available for their construction), it is perceived that the ways in which the questions to students are used are distinct. Both teachers use the questions (because they used the same material) but their role in the class development was different. Teacher-A tried to develop the subject starting from the discussion and teacher-B used the questions as a complement, after discussing the subject with the students.

Teacher-A also gave more time for students to think about the questions and tried to make them discuss between them before the teacher's intervention. By stimulating students to work on their own, the task became more real to a greater number of students. This could stimulate everyone to participate and involve students in cognitive processes which might help them to consolidate their learning, by becoming more significant, anchoring new knowledge on the old knowledge [18]. In this way the knowledge could be constructed inside the classroom and the students could feel themselves as an integrating part of the class [19]. The time issue is very important to class management and both teachers refer it, but teacher-A allowed for the discussions to take place anyway, because he believed that a greater value could come from them. Teacher-B seemed more reserved about the value of discussions and considered that doing those discussions rapidly with all students led to similar outcomes were and saved time.

Students Perceptions

At the end of the semester students were invited to answer a questionnaire about their perceptions [20]. The first part referred to students' level of agreement concerning the way classes were develop and also students' attitude inside and outside the classroom; the second part referred to their level of agreement about some statements concerning their interest in the course and in learning physics. The results, for both teachers, are summarized in Figure 2 (each graph referring to one of those parts).

In general, students' perception of classes, classroom discussions, after-class interaction and their learning, are better in the case of teacher-A. Similar results are found concerning students' ideas of themselves.

Confronting these results with the mediation characterization, in which teacher-A provided more discussions between students, allowing enough time for them to think on their own, we can assumed that this led to a better students' perceptions. From the data collected, teacher-A students are more willing to continue those discussions after class. So, a teacher mediation that stimulates students to think about the problems and knowledge mobilization may foment self regulation and contributes to the development of students' intrinsic motivation for learning.

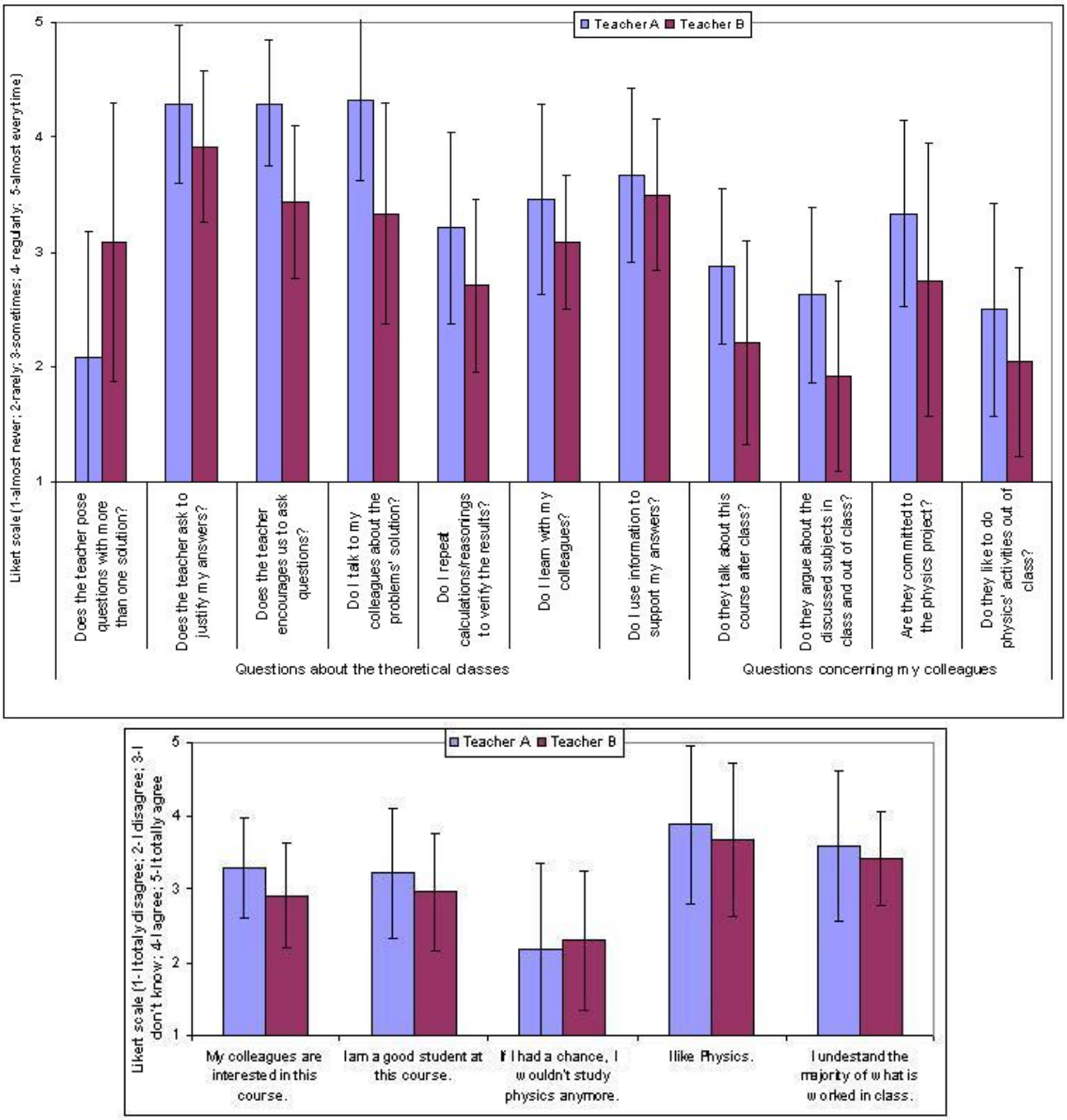

FIGURE 2
STUDENTS PERCEPTIONS ABOUT TEACHING AND LEARNING

Students Development of Competences

Before the analysed subject (heat transfer) had been discussed in class, the teachers presented students with a competence and knowledge test (adapted from Thornton & Sokoloff [21]). Its objective was to infer students' prior knowledge and measure the gains after the topic was explored in the classroom. We present these results in Figure 3. The results were analysed using the modified gain c [22], which represents the normalized gain [23] if post > pre; it does not consider results if pre=post=100% or 0%; considers c=0 if pre=post; and in the case of post > pre, c becomes the difference between student' result of the post and pre-test, divided by the pre-test result. The number of students is not very high, because only students who attend both tests are considered (in Figure 3, each point represents one student).

It can be observed in Figure 3 that the teacher-A's class achieves better results, both on the pre as on the post-test, with nearly 40% of the cases above the line corresponding to c=40%, comparing to only 21% of teacher-B students in these conditions.

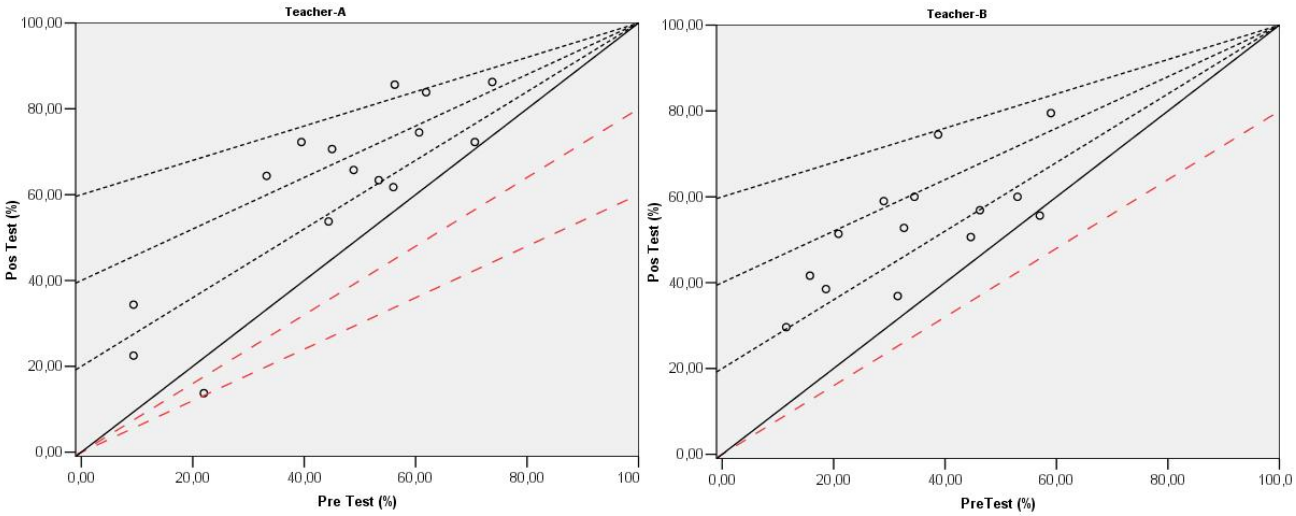

FIGURE 3
PRE AND POST TEST COMPARISON BETWEEN THE TWO TEACHERS

Teacher Reflections upon the Effected Mediation

Teacher-A was not only able to produce a self-reflection, but he could also support his allegations by comparing with the mediation performed by the other teacher. This micro analysis, based in the real events that occurred in seconds or minutes of the class time, allows clarifying important aspects that might influence students' learning. This could lead to identify effective mediation traces and point possibilities of improvement. Some of the relevant aspects, based on teacher-A reflections were:

- The importance of capturing students' attention before the beginning of a different subject discussion or the developing of new knowledge. This became very clear in the multimodal narratives which allow showing its importance to other teachers more easily.
- Sometimes, during the discussions, the teacher does not hear out every student's comments (because they speak at the same time or very softly). This may not be encouraging if it happens to the same student more than once. The teacher must develop a more efficient way of collecting student's ideas and contributions, for instance by forming groups of discussion and then ask each group to deliver their conclusion.
- All arguments presented by the students should be considered, even when the teacher decides not to explain them in that particular moment, they should not be forgotten. Each contribution can simply be record on the whiteboard and then erased if and when no longer necessary.
- The importance of allowing enough time for the proposed discussions. Probably, it becomes more productive to discuss fewer issues, but let the students do some autonomous thinking about them.
- Shortly before the end of class, the teacher can bring up a conceptual question, with connections to students' daily life in order to motivate students to get out of the class thinking about physics and hopefully discuss it with each other after class.
- Use conceptual questions into two steps: first by only showing the question, forcing students to mobilize their knowledge; secondly, some hypothesis may be showed, allowing students to choose and discuss their choices before teacher's intervention.

DISCUSSION AND CONCLUSIONS

The teacher reflection allows to base curricular modifications, helps to clarify the tasks and the right moment to present them, in order to potentiate the students' learning. It also helps to establish a more productive design of teacher mediation in the classroom: the students became more active, their autonomy and collaborative work was promoted. Different ways of monitoring students' learning were studied and a more effective feedback system was developed. It was understood that, even though some students felt motivated by a formative assessment and even when the teacher mediation helps showing its importance, the majority will only take it seriously if there is a quantitative assessment.

The teacher's attention in his/her mediation allowing students to have a truly active role within a classroom (even in a theoretical lesson), can be compensated not only in terms of students' involvement, motivation and interest but also in a higher level of skills developed. Even though the two teachers tried to have this concern, teacher-B was very conditioned by the time he thought he was spending and this fact was always dominant. This highlights the fact that, even though teachers may be receptive to change, their educational beliefs are difficult to overcome. These changes require learning and maturation, to fully understand their long term benefits.

Teacher-B develops the lesson based on information transmission, alternating with moments of discussion with the class, but by doing it with the whole class at once he restricted this discussion to a secondary role and to a set of more expeditious students. Teacher-A presents a closer perspective of an attempt to construct knowledge with students, making the classroom an environment for social learning. The results point to better results in students' perceptions about teaching and learning, as well as competence development in a wider set of students.

This reflection also permitted to clarify the importance of some particular aspects of a real class, pointing to ways of improvement, using the multimodal narratives as a means to easily show those aspects to other teachers.

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REFERENCES

[1] W. Leonard, W. J. Gerace, R. Dufresne, and J. Mestre, "Concept-based problem solving: Combining educational research results and practical experience to create a framework for learning physics and to derive effective classroom practices", University of Massachusetts 1999.

[2] L. C. McDermott and E. F. Redish, "Resource letter on Physics Education Research", *Am. J. Phys.*, vol. 67, 1999.

[3] J. P. Mestre, "Implications of research on learning for the education of prospective science and physics teachers", *Phys. Educ.*, vol. 36, 2001, pp. 44-51.

[4] E. F. Redish, "The implications of cognitive studies for teaching physics", *Am. J. of Phys.*, vol. 62, 1994, pp. 796-803.

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

[6] P. Ramsden, *Learning to Teach in Higher Education*. London: Routledge, 1992.

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

[8] R. M. Felder and R. Brent, "How to Improve Teaching Quality", *Quality Management Journal*, vol. 6, 1999, pp. 9-21.

[9] J. Mason, *Researching Your Own Pratice. The Discipline of Noticing*. London and New York: Routledge, 2002.

[10] L. Cohen, L. Manion, and R. Morrison, *Research Methods in Education*, sixth ed. London and New York: Routdlege Falmer, 2007.

[11] C. Viegas, J. B. Lopes, and J. P. Cravino, "Incremental Innovations in a Physics Curriculum for Engineering Undergraduates", in *Innovations 2009*. Arlington, VA, USA: iNEER, 2009, pp. 175-186.

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

[13] 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, 2000, pp. 26-39.

[14] J. Hattie and H. Timperley, "The Power of Feedback", *Review of Educational Research*, vol. 77, 2007, pp. 81-112.

[15] J. Biggs, *Teaching for Quality Learning at University*. Buckingham, UK: Open University Press, 1999.

[16] J. B. Lopes, C. Viegas, J. P. Cravino, "Improving Learning of Physics and the Development of Competences in Engineering Students", *IJEE*, vol. 26, 2010, pp. 612-627.

[17] J. B. Lopes, J. P. Cravino, M. Branco, E. Saraiva, and A. A. Silva, "Mediation of student learning: dimensions and evidences in science teaching", *PEC 2008 - Problems of Education in the 21st Century*, vol. 9, 2008, pp. 42-52.

[18] D. P. Ausubel, *The Acquisition and Retention of Knowledge: A Cognitive View*: Springer, 2000.

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

[20] K. Scantlebury, W. Boone, J. B. Kahle, and B. J. Fraser, "Design, Validation and Use of an Evaluation Instrument for Monitoring Systemic Reform", *Journal Of Research in Science Teaching*, vol. 38, 2001, pp. 646-662.

[21] R. K. Thornton and D. S. Sokoloff, "Heat and Temperature Conceptual Evaluation, Tools for Scientific Thinking": Centre for Science and Math Teaching, Tufts University, 1987.

[22] J. D. Marx and K. Cummings, "Normalized Change", *Am. J. of Phys.*, vol. 75, 2007, pp. 87-91.

[23] 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, 1998, pp. 64-74.