Student centered teaching activities in secondary schools and misconceptions evolution: basic mechanics

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Abstract. Based on constructivism and cognitivism we believe that learning physics in schools can be faced as a process of reshaping students’ mental models about Nature’s behavior. These can correlate with existing physics misconceptions. Aware of the negative consequences of basic cognitive misunderstandings and believing that their correction, implying active and motivated students, should start from first contacts with physics knowledge in lower secondary schools, we asked three schoolteachers to participate on a pilot study with 7th, 8th and 9th graders. This study is specifically designed to promote and coach teachers’ attitudinal changes towards stronger student centered teaching behaviors. We report results obtained during academic year 2017/2018, some qualitative (from teachers diaries and recorded interviews) and a quantitative quasi-experimental study (with pre- and post-tests and control groups) with 9th graders, searching for misconceptions evolution on basic mechanics. The results obtained with 15 out of the 30 questions of the Force Concept Inventory indicate a fairly high average normalized gain for the experimental group. However, this average gain was not uniformly distributed along every FCI question, evidencing some difficulties with Newton’s 3rd law understanding. A recommended approach for its teaching in 2018/2019 produced evidence of deep learning of every tested mechanics concept.

1. Introduction
This communication reports the preparation, the development, the results and further consequences of a pilot study designed to produce in-practice experimental evidence to influence in-service physics teachers into changing from almost only teacher centered methodologies into much more student centered ones. The basic ideas and fundaments of this project were described with detail during the 2017 FFP15 meeting [1] and are part of an extended abstract submitted and accepted, but not yet published. This led us to presenting here only a very short summary of this work’s context and background.

Even at the birth of XXI Century, a large amount of physics teachers continue to process their professional duties using mainly teacher centered methodologies based on in class expositive sessions [1-4]. They are influenced by the behavioristic conceptions of teacher education of last century, where priority was given to careful lessons’ planning and to keeping classroom practices as close as possible to what was planned, independently of the different students’ reactions. To justify this teacher centered behavior teachers invoke long curricula, shortage of teaching time, discipline control difficulties and lack...
of published materials to help supporting discussion activities [1-3]. Sometimes teachers also recognize having educational deficiencies either in physics and/or in pedagogical knowledge.

Recent educational research based on constructivism points towards the higher efficacy of student centered teaching activities in schools [1-4] associating physics learning with the development of students’ mental models [1,5,6]. Parallels are established between researchers’ activities to produce new scientific theories – actively presenting ideas to colleagues, explaining and discussing them, experimenting and analyzing experimental results, producing theoretical and empirical arguments – and students’ efforts to try to understand the physics models taught in schools [1,4-6]. It is recognized that each of those activities has to be present in students’ centered physics teaching [1-3] and a strong emphasis on the implementation of group work strategies in schools is recommended. Very recently, OECD and Portuguese government documents [7,8] emphasize the need of transferable students’ cognitive, social and attitudinal competences development believed to be most useful in a rapidly changing world, highly uncertain about eventual future professional demands.

The research questions orienting this study are the following:

- Will teachers’ awareness about the existence and ways of development of students’ mental models induce an attitudinal change on in-service physics teachers, imposing a stronger student centered teaching behavior sustaining discussions, arguments and meaningful questioning in the classroom? How will students react to this change?
- Will this attitudinal change influence existing students’ misconceptions from first school contacts with physics teaching?

2. Preparing the pilot study

We have planned a practice-based educational research project [9] under the orientation of two university professors of Didactics of Physics with a long practice as in-school stage supervisors of future physics teachers. It started early September 2017 with a pilot study involving the collaboration of three schoolteachers with a large teaching experience. The results and details of this pilot study will guide future extended replications inserted within in-service teachers’ education courses [1,10].

2.1. Choosing the cooperating school teachers

To be able to correctly accomplish physics teaching in lower secondary school levels, teachers have to understand deeply the contents of classical physics and its limits, complemented with some knowledge of atomic and nuclear physics, of quantum mechanics and of relativist theories. Inserted in their educational studies, they must acknowledge the main contents of behaviorist, constructivist and cognitivist theories of learning, understanding their different implications on the need of different modes of teaching [1,6,11,12]. They also have to be aware of the importance of pedagogical content knowledge [13] enabling the transformation of mathematical abstract scientific models into conceptual laws understandable by young students.

Teachers must be able to keep their students actively motivated using daily life situations to illustrate physics concepts and laws [1,14]. Specifically for physics teaching, they must know and understand the necessary building of correct physics knowledge structures, based on students’ previous knowledge [1,15]. This points out to the fundamental importance of teachers abilities to detect misconceptions and to be able to work adequately for their correction. Last – but not the least – physics teachers should have enough epistemological knowledge [1,4,16] to understand how new scientific theories develop and have to be accepted by the scientific community. Teachers must be aware of the efforts they are demanding from their students when trying to teach them new physics concepts and laws. In fact one wants students to develop/correct their own mental models creating new cognitive connections with the previously acquired knowledge, up to the point of finding by themselves solutions for different problematic situations. We are educating students in secondary schools to reach the level of creativity [17].

Teachers need not dominate every physics, educational and pedagogical content knowledge. However they should know and understand it deeply enough to be able to perceive their own flaws
and to demand educational complements whenever they feel their need – which was one of the main reasons for the implementation of in-service teachers' education.

We had all these conditions in mind when we purposely selected the three co-authors of this work to collaborate in the project with their school teaching and their students’ learning. Each of them, with more than 20 years of teaching experience in lower and upper secondary schools, had completed a five years university degree in physics (educational branch) followed by a complementary two years master’s degree in physics teaching, developed in parallel with school teaching. One of them (MVS) has also obtained a PhD in physics teaching, having a large experience on educational research.

2.2. Educating the school teachers for what was expected from them
About 20 years ago our collaborating teachers completed a traditional pre-service teacher education, influenced by behaviorism. Despite of the consequent academic education, they told us that they have heard of constructivism and cognitivism, as well as of mental models, but always in a very light and disconnected way. Hence it was decided that the five of us would participate on a three hours meeting before the start of the yearly academic duties, to dialog about physics learning and the cognitive effort asked from students when building and rebuilding the cognitive structures implied on the processing of new information within previous knowledge.

The more or less organized knowledge structures constitute students’ mental models [1,5,6]. Anyone at any stage of cognitive development possesses his (her) own mental models about Nature’s behavior, based on attempts to understand previous experiences. This is why within any classroom different students have different mental models about physics concepts and laws. Teachers cannot directly access students’ mental models. To have information about their content, either correct or not, teachers have to “force” students to speak or write or solve problems, using representations of mental models verbalized by their own words. This fact represents an extra contribution to the difficulty of teaching and learning physics, since words used in physics have special meanings, most of the times not straightly correlated with the day-by-day interpretations of the same speech [1,6,18].

3. Development of student centered teaching activities
After our three hours meeting, the collaborating schoolteachers were aware that they were expected to produce detailed information on the modifications they decided to implement on their academic activities in order to turn their teaching into a more student centered one. They should keep notes on the students’ reactions, motivation and behavior, on teaching difficulties, on new emergent ideas, on eventual disasters or successes, on possible lack of teaching time. The following subsections contain teachers’ detailed comments and are based on their written reports and on the contents of the final recorded interviews.

3.1. 7th grade
João (JJT) worked with two small 7th grade classrooms with 12 / 13 years old students, a fair amount of which with special educational needs and some coming from social care institutions. The curriculum content was astronomy, mass and weight.

“I have changed my previous teaching for about 30 to 40%, focusing myself mainly on the organization of the experimental activities. I have always thought that this new organization was the correct way of teaching physics on 7th grade, the first time pupils come into contact with a physics teacher, but up to now I could not really produce enough arguments to defend this teaching organization. Now I feel I have them and I am really pleased. I would like to be able to influence my colleagues into this way of teaching.

My first physics lessons on astronomy were mainly expositive, introducing and explaining concepts, not very much different from what I was used to do before. Afterwards I have divided the classrooms into four groups of four students with mixed abilities. Every week each group was responsible for developing more or less organized activities towards better integrating previous and new physics knowledge.

The first experimental activity of the four groups was to build a Planet Walk on the school yard. The students used the textbook to look for Solar System’s distances and dimensions. They measured
the school yard (larger distance 310 meters). They had to choose one of the available sports balls to represent the Sun. They were very surprised when they ‘discovered’ that it had to be a tennis ball. They used plasticine to build tiny spheres for some of the planets, using small pins to display them in the correct positions. Observations worth mentioning: students thought that all the planets had similar dimensions and were more or less at equal distances from each other; peer cooperation was excellent with the higher level students willing to show their capacities and being highly available to help their mates into higher levels of understanding, motivating their group mates and their whole classes; the teacher was always available to mediate discussions and to orient the students to the correct solutions whenever necessary.

In the second students’ challenge, the students were given a torch and two balls of different sizes. They were expected to try to explain to their mates’ one of the following situations: succession of days and nights; why on Earth it is simultaneously winter in Portugal and summer in Brazil; the existence of a dark side of the Moon; why Moon and Sun eclipses do not occur every month. The students were given steps to follow: 1st: a discussion within each group of four students on what could be done to explain any of the situations; 2nd: possible solutions were presented to the whole class and were written on the board, with some general discussion supervised by the teacher in order to detect common suggestions; 3rd: every group was given one of the different situations to prepare an explanation to the whole classroom. Observations: students were already aware of Earth rotation, so it was not difficult to explain the succession of days and nights; only two students knew the consequences of the inclination of Earth’s rotation axis, all the others mentioned the distance Earth-Sun; no student was able to produce any explanation either about the dark side of the Moon or the eclipses’ behavior. The teacher suggested internet searches for every group and helped everyone to choose the best alternative experimental exhibitions with the material they were given. The students were successful with their explanations.

The third challenge was: can we measure the mass of the laboratory keys using a rubber band? Each group was given a set of marked masses, a ruler and a rubber band. Once again the students had to follow some steps: 1st: to discuss within each group what could be done to answer the question; 2nd: the conclusions had to be explained to the whole classroom. After this step everyone understood that the length of the rubber band supporting the marked masses depended on the suspended mass. This would allow them to determine the mass of the suspended keys; 3rd: comparing the obtained values with the measurements obtained with a balance, students were surprised by the lack of agreement; 4th: the teacher opened a discussion on whether building a graph with the marked masses versus the rubber band lengths would help to find the solution. Using one of the groups’ data the teacher explained how to do it; 5th: every group draw graphs with the collected data. They could find the keys mass, which they saw finally that agreed with the readings on the laboratory balance. Observations: it was very difficult for the students to determine the graph scales and to locate the measured points on the graph; however after the graph content had been understood by anyone, one group suggested the use of three rubber bands to measure larger masses. The whole process of a graph building was repeated with improved rigor and higher easiness”.

General comment: It was the first time this teacher developed the first two challenges with 7th grade students; JJT mentioned the high value of this student centered active orientation able to motivate every student and leading to a very good behavior in physics classrooms of these otherwise generally problematic students. He wrote: “it is more a ‘way of life’ than a methodology: it builds empathy, impossible to be created with a ‘traditional’ expositive teaching. Students got used to the idea of measuring everything; and one of them mentioned that ‘formulas in physics are not merely more equations on the board, because they always serve to explain some physics behavior’.”

3.2. 8th grade
António (AJP) worked with a classroom with 25% very good students, 25% with great difficulties (special educational needs) and 50% of medium ability. Students were 13 / 14 years old. The curriculum content was sound and audition; light and vision.

“I have used a student centered teaching approach I could characterize as ‘give some impulse to high achievers, let them go their own way to extend their mental models and use extra time to attend
less able students’. From what I used to do before, I have changed my way of teaching in about 50% and I felt that my students enjoyed it very much.

After short introductions to new physics concepts and laws, always using some contextualization on daily life, I frequently asked the students to tell me and their colleagues, using their own words, what they had understood from my presentation and how its content would fit with their previous learning. Following any student intervention I asked another student to make some comment: ‘Do you agree? Disagree? Why?’ Students had to use their own words and their speeches were corrected whenever necessary, by colleagues or by myself. This way I led students to reflect about their own understanding, connecting new knowledge with previous one, mainly when solving problematic situations. The more autonomous students were often allowed to go to the school library where the school computers are located and a librarian is present to help students. The students could search information and make inquiries about sound and electromagnetic waves applications, preparing a written report to the teacher and afterwards a presentation of the result of their searches to the whole classroom. Meanwhile the teacher had more time to fulfill the needs of the less able students, preparing them to accept their colleagues’ explanations. Examples of applications: ‘watching’ sound in mobile phones, the role of microphones, different uses of electromagnetic radiations. The students’ motivation increased a lot due to the different active roles attributed to the students”.

3.3. 9th grade
Marta (MVS) worked with a 20 students’ classroom, 14 / 15 years old, three of them with special educational needs. The number of students was somehow reduced towards the end of the semester. The curriculum content was: basic mechanics, 1D, no reversal.

“I could not see any need for complete change of anything I used to do before. I only had to adapt it to the idea of, as a teacher, my role being to help the students to build their own mental models. It was more an attitudinal change. The students were used to my previous way of teaching, because I had been their teacher last year. I had to explain them why I was going to require from them something a bit different. Hence, my first lesson was on the existence and meaning of mental models and on the way they can be developed through students’ own efforts. We discussed the need of students being active and motivated in the classroom, in order to be able to correctly process the ideas that ‘feed’ their mental models, which grow through inserting new information within previous learning. I talked about possible previous students’ misconceptions (association of ideas needing correction), which only the students can correct themselves, with teachers’ help.

Aware of the convenience of contextualizing new knowledge and of showing how basic physics concepts and laws are worth knowing by any citizen, besides textbook recommended experiences I have also created experimental activities based on Road Safety Suggestions distributed by the Portuguese Government to every school under a project of Education for Health. In groups of two, the students had to observe carefully the car movements on the roads surrounding the school building, had to make measurements, to build data tables, to draw x(t) graphs and to calculate average velocities. After analyzing statistical data on car accidents their attention was called for the speed limit signs; students had to detect whether the legal rules had been obeyed by the observed drivers. After measuring their own reaction time when a colleague dropped a vertical ruler, students calculated safe breaking distances for the cars they have observed.

I would say that I have changed my teaching up to about 30 to 40%, keeping in mind that the students have to learn, understand and draw conclusions for themselves. Mainly, I have re-organized every experimental protocol: in groups of two or three, students were encouraged to collaborate with each other as a team, to discuss possible different ways of developing the experimental work, to perform the experiment, to measure results, to calculate averages and to draw graphs, to discuss eventual conclusions and write them down, to correlate them with previous learning and to prepare a communication for the whole classroom. These activities generally fulfilled two out of the three hours of the allocated weekly timetable.

I was careful with the correction of physics language and, at a certain stage, the students started correcting their own and their colleagues’ speech. During whole class sessions devoted to concepts and physics laws presentations, as well as to comments on students’ questions, I have induced a ‘let’s
think aloud’ attitude, discussing everything with students’ collaboration. These sort of changes become natural when one keeps in mind the mental models and the students’ centered teaching perspective: students have to solve situations by themselves – duly helped – discussing deeply what they are learning.

Students enjoyed being active participants in every classroom activity, instead of merely watching and listening to what was going on. They have recognized that they were ‘learning better’. Teachers should make students feel that, in a certain way, they are ‘discovering’ things by themselves – in fact, if let alone, it is impossible for them to arrive at new physics theories and laws [1], but, in successful classrooms, they must feel that they are really creating their own new knowledge”.

4. Student centered teaching and misconceptions’ evolution

Physics content are concepts and laws belonging to theories about Nature’s behavior, consistently developed along five centuries by a lot of scientists to make it understandable by human beings [1]. Physics theories were used to build machines and apparatus in order to replace what used to be animal’s or human’s labor. Nowadays one does not need to light a fire or a candle to be able to see at night and one has reached the point of being able to fly overseas or even towards other planets. We travel daily in motorcars which are controlled by friction forces. We can talk directly to people in a faraway country or even see them. We can see the inside of human bodies, either directly or via special imaging technologies. In fact, due to very different applications of physics knowledge we live in a technologically developed world. Hence it is of the highest importance that everyone understands the basic concepts and laws of physics [1].

Since childhood we see things falling to the ground, when simply released. Some fall very quickly and others more slowly. We see birds flying. Almost without noticing it, everyone builds own naïve empirical ways of understanding what one observes happening around oneself. We build incipient mental models about physics contents, but in general they are not correlated with scientific theories. These scientifically incorrect ways of trying to understand what surrounds us are called misconceptions. Due to observations and questions either answered by family, friends or schoolteachers, children build a lot of misconceptions on physics content before coming into contact with physics teaching in schools (7th grade).

Physics words are used in daily language, but their meanings are different. During the first contacts with schooling students listen to and use some physics words without really knowing that most of them do not keep equivalent meanings as in daily life [18].

If unnoticed, hence uncorrected, misconceptions can grow stronger with further experiences, misunderstood school teaching and the development of cognitive competences with age [19]. Through student centered activities, with argumentations, frequent dialogues and written reports, teachers can easily detect misconceptions and should correct them, contributing to avoid the propagation of students’ physics misunderstandings.

In this work we have developed a quasi-experimental quantitative study with 9th graders on 1D no reversal basic mechanics. We compare the misconceptions’ evolution of an experimental group formed by MVS pupils (see section 3.3) with that of control groups of the same school, taught via traditional teacher centered methodologies. Every student answered a pre-test before starting the study of basic mechanics and a post-test (equal to the pre-test) at the end of the school activities. The measuring instrument was a straight translation of 15 out of the 30 questions of the revised FCI [20], focused on this basic mechanics content. Unfortunately control group B answering the post-test had to be different from control group A answering the pre-test, due to teaching time constrains. However we believe that this makes no meaningful difference.

The obtained results are displayed on table 1 and on figure 1. Table 1 shows that at the beginning of the study, before school teaching of any 9th grade physics, the experimental and control groups were very equivalent, both with a large amount of misconceptions detected by the measuring instrument. For the two control groups one can notice no meaningful difference between pre and post-tests, evidencing almost no
effect on misconceptions correction induced by almost only teacher centered methodologies of traditional teaching. However, for the experimental group the pre- to post- test differences are considerable, leading to an average normalized gain \([21] <g> = 0.51 \pm 0.13\), revealing meaningful learning (\(<g>\) higher than 0.30).

| Number of students | Average pre | Average post | Average \(<g>\) |
|--------------------|-------------|--------------|-----------------|
| Control group A    | 24          | 0.15 ± 0.12  | ---             |
| Control group B    | 38          | ---          | 0.17 ± 0.11     |
| Experimental group | 17          | 0.15 ± 0.08  | 0.58 ± 0.09     | 0.51 ± 0.13 |

Figure 1 shows a plot of the individual percentage normalized gains versus pre-test results for every student of the experimental group (point [1;0] is not a data point, but only a convenience for drawing the 30% straight line [21]). Every student of the experimental group had a \(<g>\) value above 30%.

Although the overall result is good, the experimental group normalized gain of 0.51 is not uniformly distributed along every mechanics’ concept of FCI questions. A closer look at the results shows that the improvement on misconceptions correction was clearly very high for eight questions (see table 2) with a partial \(<g>\) value of 0.84, and not so good for the remaining seven ones with \(<g> = 0.13\) (see table 3).

| Q1 | Q3 | Q13 | Q17 | Q25 | Q27 | Q29 | Q30 | Average |
|----|----|-----|-----|-----|-----|-----|-----|---------|
| %  | %  | %   | %   | %   | %   | %   | %   | %       |
| Pre-test | 20 | 25  | 5   | 10  | 35  | 35  | 20  | 15      | 21%     |
| Post-test | 100| 94  | 100  | 78  | 78  | 72  | 83  | 89      | 87%     |

Table 3. Percentages of correct choices from MVS experimental group, 2017 / 2018.
For instance, the results on the four questions on Newton’s 3rd law, Q4, Q15, Q16 and Q28, give a $<g>$ value of only 0.24, slightly lower than what can be called meaningful learning [21]. Hence we have decided that some improvement on Newton’s 3rd law teaching should be tried, in order to promote meaningful understanding.

5. Newton’s 3rd law
The misconceptions associated with Newton’s 3rd law are well known [22,23]. We have just shown with our study that even students who understand well most of the fundamental contents of mechanics concepts (see Table 2) were not able to apply correctly this law.

This effect could be a consequence of the generalized use of the words ‘action’ and ‘reaction’ when teaching Newton’s 3rd law, following a straight translation of its original proposal by Newton. However the use of these two different words for two effects which cannot be distinguished (which is the action? which is the reaction?) can induce wrong pedagogical consequences [23-25]. In fact in day-by-day language any action precedes an eventual reaction. In this sense, there is a time delay in between action and consequent reaction. Furthermore, in day-by-day situations, actions and reactions can be quite different.

On the contrary in Newton’s 3rd law the two forces always present in an interaction between two bodies act simultaneously, each one being applied on one of the bodies by the other: body A exerts a force on body B and simultaneously body B exerts a force on body A. The two forces have exactly the same intensity and opposite directions. In fact, they are really two simultaneous actions on the two interacting bodies.

Sometimes students say that “the first body to act”, or the “more active body” exerts a more intense force on the other [22]. By “more active” they mean either the one somehow on the top of the other, or the one which is moving before the impact. It can also happen that, due to the word ‘reaction’, the student’s focus their attention on what happens after the interaction. When the colliding bodies have different masses, generally the less massive one suffers a larger damage. Hence students conclude that the more massive body exerts a more intense force on the lighter one.

We have discussed these comments with our collaborating teachers asking them to avoid the words “action” and “reaction” when teaching Newton’s 3rd law. This law should be referred to as “equality of two simultaneous actions”, one exerted by each interacting body on the other, with equal intensities and opposite directions. It is one of the universal laws of Newton’s mechanics. Emphasis should be located on the symmetry of every interaction and not on eventual differences between the interacting bodies, either before or after the interaction.

6. Further results
During the present academic year, 2018 / 2019, AJP worked with two 9th grade classrooms with a total of 42 students, the same ones he had taught in the previous year when they were 8th graders. He developed teacher centered activities similar to those reported by MVS on subsection 3.3, when describing her way of teaching mechanics in 9th level. However, as explained in the previous section, AJP taught the Newton’s 3rd law in the different way recommended on section 5.

Using the same 15 questions of FCI, he obtained the results illustrated on tables 4 and 5, which, for comparison, we present exactly with the same layout as the preceding tables 2 and 3.
Table 4. Percentage of correct choices from AJP experimental group, 2018 / 2019.
The same eight questions whose content was extremely well understood by MVS students

|       | Q1 | Q3 | Q13 | Q17 | Q25 | Q27 | Q29 | Q30 | Average |
|-------|----|----|-----|-----|-----|-----|-----|-----|---------|
| Pre-test | 7  | 20 | 0   | 20  | 5   | 20  | 41  | 10  | 15%     |
| Post-test | 81 | 83 | 60  | 52  | 64  | 64  | 67  | 60  | 66%     |

Table 5. Percentages of correct choices from AJP experimental group, 2018 / 2019.
The same seven questions whose content was not well understood by MVS students

|       | Q4 | Q15 | Q16 | Q19 | Q20 | Q26 | Q28 | Average |
|-------|----|-----|-----|-----|-----|-----|-----|---------|
| Pre-test | 44 | 32  | 39  | 22  | 10  | 7   | 20  | 25%     |
| Post-test | 88 | 81  | 71  | 40  | 50  | 55  | 76  | 66%     |

One can notice that the 2017 / 2018 good results obtained by MVS for eight of the questions were somehow repeated with the 2018 / 2019 students, although with a smaller partial <g> value of 0.60; however, the Newton’s 3rd law misconceptions (Q4, Q15, Q16, Q28) were, now, also meaningfully corrected up to the same level as the remaining questions, with a partial <g> value of 0.68.

7. Conclusions

Following the initial research questions we can say that it was possible to influence in-service physics teachers to change about 40% of their teaching activities, in order to turn them into much more student centered ones. This happened mainly by promoting more group work and complementary dialogic opportunities, either group or whole classroom ones. Our cooperating teachers recognized these changes as being a natural consequence of thinking about physics learning as the enlargement/development/correction of students’ mental models on Nature’s behavior. New taught ideas need to be processed by the students through interaction with previous knowledge, which we all start developing since birth in contact with own environment, family and society. This knowledge processing becomes highly demanding when children go to schools and our study shows that it can only be correctly accomplished by motivated students, feeling that they are actively participating in their own learning: as far as school learning is concerned student centered activities led to substantial misconceptions correction as compared with traditional teaching.

Our collaborating teachers felt that through promoting active dialogic and collaborative ways of learning they were developing teacher-student and student-student empathy, as well as students’ positive attitudes towards school and the learning of physics. The implementation of student centered activities has produced neither shortage of teaching time nor undisciplined students’ behavior. On the contrary, usually problematic students some with educational special needs have shown a greater interest towards physics classrooms. Finally some complementary recommendations about teaching Newton’s 3rd law have produced very positive students’ learning results.

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