JOURNAL OF BALTIC SCIENCE EDUCATION
ISSN 1648-3898

IMPROVING STUDENT UNDERSTANDING OF THE CONCEPTS OF WEIGHT AND MASS WITH A COMPUTER SIMULATION

Cândida Sarabando,
José P. Cravino,
Armando A. Soares

Abstract. *Although weight and mass are considered fundamental concepts in physics, they are still not well understood by students. A computer simulation was designed to improve students' learning of these concepts and compared it with other teaching strategies. The research was carried out with 142 students (7th grade; 12-13 years old), from three schools. There is a significant change in conceptual understanding of the concepts weight and mass for all groups. Nevertheless, total gains were higher for students who used the computer simulation. The implication is that using a computer simulation, carefully designed to address specific conceptual difficulties, may help the students understand the concepts of weight and mass. We also interviewed teachers to understand their role in the classroom. It was found that the features most likely to contribute to improve students' learning are related to the balance between support and autonomy given to students during the use of the computer simulation.*

Key words: *computer simulation, teaching and learning, physics education, mass and weight.*

Cândida Sarabando, José P. Cravino, Armando A. Soares
University of Trás-os-Montes and Alto Douro, Portugal

Introduction

The Concepts of Mass and Weight

The students' learning about the concepts of weight and mass has raised interest in research over several decades. Most of these studies have been descriptive, with the aim of cataloging alternative conceptions of students (Galili, 2001; Philips, 1991; Sequeira and Leite, 1991; Tural et al., 2010). Students' ideas and interpretations, based on everyday experiences and language, often interfere with learning of the scientific models introduced during science lessons, and affect the ability of students to assimilate the scientifically correct ideas (Zacharia, 2007). Mullet and Gervais (1990) showed that the concepts of weight and mass are both understood as one concept, that of weight, whereas the expression "quantity of matter" is clearly related with the concept of mass.

Although the concepts of weight and mass are considered fundamental to the teaching of physics, they are still not well understood by students (Gönen, 2008), resulting in the need to use consistent definitions (Hecht, 2006, 2011; Morrison, 1999).

Traditionally there have been three common approaches to defining mass: (1) as quantity of matter, (2) as that which resists changes in motion, and (3) as that which gives rise to the gravitational interaction. The first approach came out of the Middle Ages and its metaphysical musings (Jammer, 1997). As a rule, when quantity of matter is proffered as the definition of mass, it is linked to the "amount of stuff". The second approach goes back to Newton's second law (Hecht, 2011). This definition is based on the idea of inertia – the mass of an object is a measure of, and gives rise to, its resistance to changes in motion (inertial mass). The third approach evolved from the law of gravita-

ISSN 1648–3898

tion and maintains that mass is that which gives rise to the gravitational interaction (gravitational mass). For 7th grade students, who are learning this concept for the first time, the official Portuguese curriculum defines mass as "quantity of matter", and it is sufficient to know that the mass of an object depends on what the object is made of and how much, and is not dependent on where it is or what it is doing (Jameson, 2006).

The concept of weight, like the concept of mass, is one of the most fundamental concepts in physics. In the literature two definitions of weight are presented (Galili, 1993, 2001; Galili and Lehavi, 2003, 2006; Tural et al., 2010). First, the gravitational definition identifies weight with gravitational force exerted on a body (the "gravitational weight" approach). This account of weight draws on the long tradition starting from Newton. In its modern version, this instruction splits into true weight, the gravitational force itself, and apparent (effective) weight, which corresponds to the weighing results (Hecht, 1994). The true weight is depicted by the Second Newton law: W = mg.

The second, operational definition, associates weight with the contact force. The notion of "operational weight" entered physics in the 20th century. In this approach, weight is distinguished from the gravitational force and is defined operationally as a result of a weighing procedure (see Figure 1 – adapted from Galili, 1995).

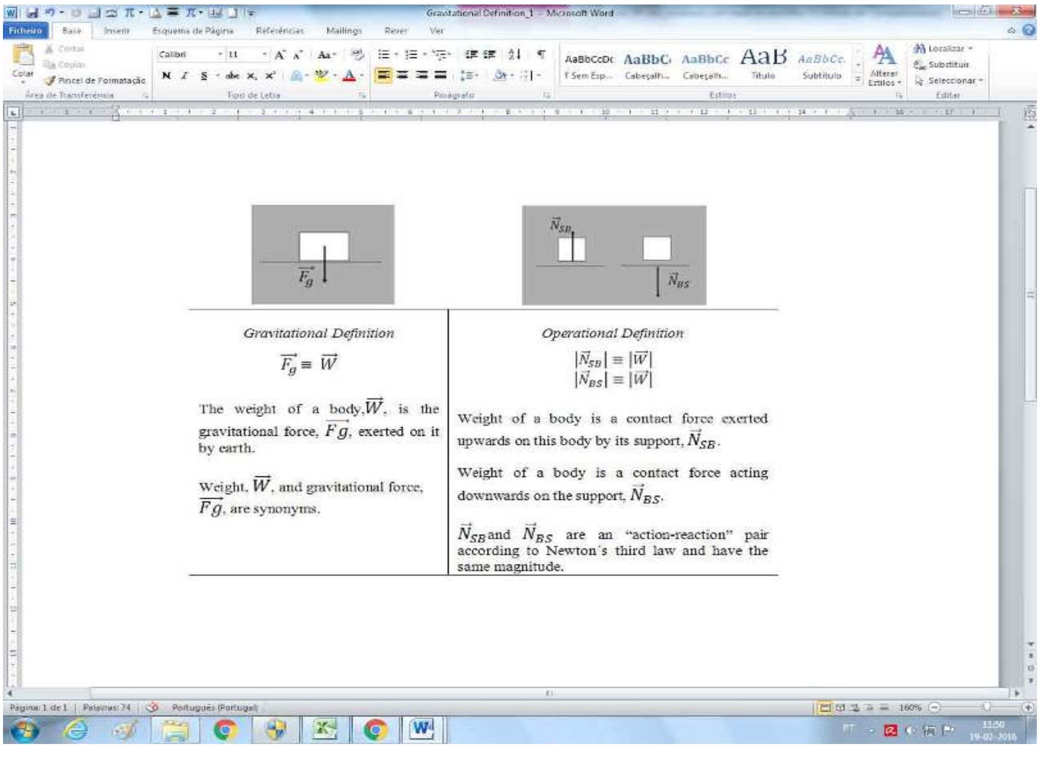

Figure 1: Weight definitions.

Different concept definitions – gravitational and operational – have different pedagogical implications: The central implication of the operational definition is the split between the two concepts: weight – the heaviness of a body measured in weighing and referring to the force exerted by the body on its support, and gravitational force which stands for the force of attraction between any two bodies. In fact, it is a conflict between two frameworks, which provide entirely different accounts for various situations (Stein and Galili, 2014; Stein et al., 2015).

The conflict between the two frameworks presents a nontrivial curricular phenomenon, since the two definitions provide entirely different accounts for physical situations. Commonly, science instruction in elementary schools defines weight as the heaviness of things measured by a calibrated spring. In middle and high schools, however, physics theory enters class instruction. Weight is distinguished from mass and is often defined as the force of gravitation exerted on a particular object ("gravitational weight" approach). The complexity of this pedagogy can be appreciated if one pays attention to the conceptual break: the heaviness of objects is directly associated with weighing results and so corresponds to the operational definition. Instead, when weight is equated with the gravitational force, weighing results become unreliable since the interpretation of weighing is not univocal. This is because weighing results may be influenced by motion (acceleration, spinning, free falling). The two definitions of weight, operational and gravitational, thus, may contradict each other in a variety of situations (Stein and Galili, 2014).

The official Portuguese curriculum for the 7th grade states that students should distinguish the concepts of weight and mass (namely that mass is a scalar quantity and is conserved; and that weight is a vector quantity that is different in each planet of the solar system). Therefore, the curriculum also states that students should compare the variation of weight of an object in different planets of the solar system (for example, the Moon and Jupiter), calculating the value and representing the vector. The definition of weight in the official Portuguese curriculum is "the gravitational attraction force that a planet exerts in a body". For this reason, in this research, we considered the gravitational definition of weight.

Although the concepts of weight and mass are taught for the first time in the 7th grade in Portugal, students have heard these terms before in everyday life or in school. However, the way these terms are used in everyday language is not correct and teachers in previous school levels often are not careful enough with the language and may eventually reinforce incorrect meanings about these concepts.

Computer Simulations in Education

The evidence based on experimental studies suggests that we can improve learning by integrating computer simulations on topics that students find conceptually difficult (Webb, 2005). Given all the previously mentioned aspects, we focused on the use of new technologies of information and communication, particularly computer simulations, as a possible contribution to the problems described, regarding the difficulties that basic school students show in learning the concepts of weight and mass.

The computer simulations are designed to facilitate teaching and learning through visualization and interaction with dynamic models of natural phenomena (de Jong and van Joolingen, 1998; Perkins et al., 2006; Wieman et al., 2008). They offer idealized, dynamic and visual representations of physical phenomena and experiments which would be dangerous, costly or otherwise not feasible in a school laboratory (Hennessy et al., 2007). Since the computer simulations show simplified versions of the natural world, they can focus students' attention more directly on the desired phenomenon (de Jong and van Joolingen, 1998; Perkins et al., 2006; Wieman et al., 2008). Additionally, computer simulations may allow students to visualize objects and processes that are normally beyond the user control in the natural world (de Jong et al., 2013). In comparison with textbooks and lectures, a learning environment with a computer simulation has the advantages that students can systematically explore hypothetical situations, interact with a simplified version of a process or system, change the time-scale of events, and practice tasks and solve problems in a realistic environment without stress (Rutten et al., 2012).

Previous studies have shown the effectiveness of computer simulations on student learning. Many of these studies focused on acquiring knowledge of specific content (Trey and Khan, 2008; Huppert et al., 2002). Some researchers also noted the success of computer simulations to develop skills of questioning and reasoning (Chang, Chen, Lin and Sung, 2008). Other investigations have reported less impressive results in the use of computer simulations in science teaching. Some of them found no advantage in using computer simulations over traditional methods (Winn et al., 2006). Further investigation also showed that the use of computer simulations was less effective than traditional instruction and hands-on laboratory strategies (Marshall and Young, 2006). Even when the students showed higher learning gains through the use of technologies such as computer simulations, some argue that this should be attributed to effective teaching methods and effects relating to the teachers (Clark, 1994). Thus, despite high expectations for the computer simulations, we cannot guarantee a general conclusion about their effectiveness (Yaman et al., 2008).

Computer simulations have become increasingly powerful and available to teachers in the past three decades (Trundle and Bell, 2010). Currently, science teachers can select from a wide range of computer simulations available through the internet. However, as far as we know, there are no computer simulations about the concepts weight and mass available in Portuguese.

The computer simulation used in this research ("Weight and Mass") was built by our team based on the *Modellus* software (Teodoro, 2000), considering student's previous ideas about the concepts of weight and mass, which are mostly associated with the weight-mass confusion. For students the concepts of weight and mass are both understood as one concept, that of weight, whereas the expression "quantity of matter" is clearly related with the concept of mass. Students tend to consider weight as an inherent and invariant feature of any object (Galili, 2001). We chose *Modellus* because it is freely distributed in the Internet and because it allows for multiple representations

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that can be seen simultaneously. For example, the user can create, see, and interact with analytical, analogous and graphical representations of mathematical objects (Neves et al., 2013; Teodoro, 2000). When exploring the simulation created for this research, students can choose a certain value for the mass of a body and observe the different weight values of the same object on different planets (Earth, Mercury and Jupiter) and on the moon and, simultaneously, they could see the weight vector representation in each of these places.

Teachers' Role in Student Learning With Computer Simulations

The inherent assumption underlying increased computer integration in the classroom is the belief that increased access will effectively enhance students' learning outcomes (Gibson et al., 2014). Because of the movement to increase educational access to computer technology, many teachers now have access to computers to use in their classrooms; however, research indicates that access to computers alone is not enough to impact teacher integration of these technologies into their classrooms or to increase student engagement (Warschauer et al., 2011;Weston and Bain, 2010).

Neither mere presence of technology nor technology awareness by itself assures that technology will be used to enhance teaching and learning. Technology implementation requires profound changes in the role of teachers and students, instructional strategies and tools, curriculum standards, and school culture. Resistance to such changes inhibits from effective integration (Koc, 2013).

The teachers' beliefs do not always reflect what is practiced (Mama and Hennessy, 2013). For example, even when they held positive perceptions of information and communication technologies, teachers' practice has often been limited to small additions to the conventional practices of teaching (Gillen et al., 2007; Hennessy et al., 2007; Webb and Cox, 2004). Teacher attitudes and beliefs are important in student engagement because these individuals are effectively the key holders to integration of computer technology and student engagement (Gibson et al., 2014). Teacher attitudes and beliefs toward the use of technology in their classroom play a major role in the extent to which they will integrate computers into their classrooms and provide their students opportunities to engage with technology for educational purposes (Hermans et al., 2008; Inan and Lowther, 2010; Lowther et al., 2003; Sclater et al., 2006).

Clearly, the efficacy of computer simulations is closely linked to the pedagogy through which they are implemented (Osborne and Dillon, 2010). Failure to take account of the pedagogy of technology use may explain some of the negative results obtained (Marshall and Young, 2006; Waight and Abd-El-Khalick, 2007). Simply provide access to computers or software without careful attention to learning support and teaching models seems to fail to produce the desired gains.

Recent surveys suggest that technology has not been effectively used for facilitating meaningful learning in the schools yet (Ertmer and Ottenbreit–Leftwich, 2010). Technology integration has been identified as a complex process affected by individual, contextual, and technical factors (Inan and Lowther, 2010; Levin and Wadmany, 2008). Although some of these have been disappearing as access to technology in the schools and teachers' relevant competency have improved, teachers' belief systems still remain as the key barrier or enabler for achieving effective technology integration (Ertmer, 2005).

The effects of computer simulations in science education are caused by interplay between the simulation, the nature of the content, the student and the teacher (Rutten et al., 2012). In order for educational innovations such as computer simulations to be successful, teachers need to be provided with the necessary skills and knowledge to implement them (Osborne and Dillon, 2010). Without proper teacher skills, the full potential of computer simulations, such as their suitability for practicing inquiry skills, may remain out of reach. Instead, they may be used as demonstration experiments or be completely controlled by the teacher (Lindgren and Schwartz, 2009). Reducing the use of computer simulations to a step-by-step cookbook approach undermines their potential to afford students with an opportunity to freely create, test and evaluate their own hypotheses in a more richly contextualized environment (Windschitl and Andre, 1998).

The role of the teacher in the classroom is an important factor affecting the use of technology in teaching and learning (Osborne and Dillon, 2010). The importance of the mediation role of teachers is well established in science education research literature (Hennessy et al., 2005; Lopes et al., 2008; Reiser, 2004; van de Pol et al., 2010). However, comparatively little research has inquired into the science teacher pedagogy of working with computer simulations (Rutten et al., 2012; Khan, 2011). So, the teacher's role is crucial in computer based environments using computer simulations.

Lopes et al. (2010) developed a theoretical model that identifies the effectiveness of a particular teaching method, to achieve certain learning outcomes - "Model of Formative Situation for Teaching Science and Technology (MFS-TST)". The MFS-TST model (Lopes et al., 2010) considers that the mediation of the teacher has two fundamental dynamics (A - interaction with the epistemic object; and B - interaction with others) and six key components (mediators, the other, epistemic objects, learning process, task / challenge of learning and learning results). The link between dynamics and components can be analyzed through ten dimensions of analysis, divided in two types (A - Interaction with the epistemic object; B - Interaction with others):

- A1 - The work really demanded from students: A task is the work demanded from students, that they must perform to reach, within a certain time, an answer to a question or other kind of request;
- A2 - Scientific and technological contexts: This concerns how the contexts and physical situations are taken into account, namely if problem solving is based in realistic contexts and if tasks are authentic;
- A3 - Epistemic and/or axiological practices: This concerns the student work in certain type of practices to construct science technology knowledge having as reference the science technology practices in the context of science technology production;
- A4 - Information: How the information is presented, used and processed. We should look for aspects like: i) what information, ii) the source of information, iii) temporal patterns of the information presentation, iv) pattern of information use and processing;
- A5 - Teacher awareness and real-time decision-making in the classroom. This concerns teacher awareness about students' learning pathway, in epistemic terms, taking into account the intended learning outcomes;
- B1 - Classroom talk: How classroom talk is considered;
- B2 - Support and authority given to students: How the student's work occurs in the classroom;
- B3 - Productive disciplinary engagement. Look for student engagement of disciplinary topics (and learning outcomes achieved) and how teacher can improve that;
- B4 - Assessment and feedback: Whatever the kind of task performed (assignments, classroom questions, self-evaluation tests, etc.), it is very important that students get proper and timely feedback on their learning outcomes;
- B5 - Learning induced: In terms of how students' learning can be extended outside the classroom.

Methodology of Research

The purpose of this empirical research is to evaluate the impact of different teaching and learning activities in improving student conceptual understanding of weight and mass in 7th grade physics and how teachers may contribute to this improvement. As discussed above, the literature indicated that computer simulations are likely to contribute to improve conceptual understanding. The same is said of experimental activities. The research was then designed to evaluate the effectiveness of three different approaches: using only "Hands-on" activities, using only the computer simulation and, finally, using both the computer simulation combined with "Hands-on" activities. This led to the first research question: is computer simulation combined with "Hands-on" activities more effective, than computer simulation or "Hands-on" activities alone, in promoting students' learning about the concepts of weight and mass?

In this research a computer simulation ("Weight and Mass") was designed and implemented in 7th grade physics classrooms and the evolution of students' conceptual understanding about the concepts of weight and mass was evaluated using pre and post-tests.

The second research question addresses how teachers may improve students' understanding about the concepts of weight and mass when using the computer simulation "Weight and Mass": what characteristics of the teacher's role when using a computer simulation contribute to improve students' learning about the concepts of weight and mass?

General Background of Research

According to the research design (see table 1), students participating in the research took a pre-test in order to characterize their knowledge with regard to the concepts of weight and mass. The students were subjected to

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the different treatments and, after the lesson about weight and mass (90 minutes), replied to a post-test (same questions as in the pre-test) to evaluate the learning achieved.

During the implementation of the intervention (see Table 1), the students of teachers A, B and C had only "Hands-on" activities in one class (class HoA) and in the other class, students of teacher A conducted "Hands-on" activities with the computer simulation (class HoA+CS) and students of teachers B and C used only the computer simulation (class CS). Before this lesson about weight and mass, students had no other lessons about these concepts.

Table 1. Research design.

Pre-test (10 minutes)		
Lesson about weight and mass (90 minutes)	Teacher A	Class HoA (25 students)
		Class HoA+CS (27 students)
	Teacher B	Class HoA (27 students)
		Class CS (24 students)
	Teacher C	Class HoA (19 students)
		Class CS (20 students)
Post-test (10 minutes)		

Students performed the experimental activities based on a written activity guide, consisting of three tasks designed to assess students' understanding of the concepts of weight and mass (see Appendix A). In Task 1, students were asked about the relationship between weight and mass of a body. For Task 2, students were asked to explain how the weight of a body relates with the mass of the planet where it is. In Task 3, students were asked to identify the main differences between the two concepts (mass and weight).

In the groups that performed only "Hands-on" activities (class HoA), students tried to do the tasks only by manipulating laboratory equipment. In the groups that performed "Hands-on" activities and used the computer simulation (class HoA+CS), the students tried to answer Task 1 using laboratory equipment and Task 2 using the computer simulation. In the groups using only the computer simulation (class CS), students tried to answer all the tasks using the computer simulation. In Task 3 students didn't use any equipment (laboratory equipment or computer simulation).

After the class about weight and mass, interviews were conducted with teachers participating in the study, to try to gather information about how they conducted their lessons.

The teaching interventions took place during the academic years 2009/2010 and 2010/2011, in a lesson of Physical and Chemical Sciences (90 minutes). In 2009/2010 a pilot study was developed by the teacher-researcher (first author of this paper) and involved the participation of 51 students (12-13 years old) from three different 7th grade classes. The pilot study allowed us to refine the activity guides and the questions of the tests.

Participants and Sample Selection

The empirical research in 2010/2011 involved the participation of three teachers of Physical and Chemical Sciences (coded A, B and C) and students from two of their classes (142 students from six 7th grade classes). Several teachers were invited, from schools in the geographical area where the researchers were based. Three teachers, from three schools of this region in northern Portugal, accepted the invitation to participate in this research. Since their students were already divided into classes, it was not possible to make a random selection of the students for the different treatments. However, the selection of which class of each teacher was assigned to each treatment was random.

Instruments and Procedures

Before the implementation of this intervention, all teachers invited to participate in this research were informed about its aims, and all aspects to be considered during the implementation with students in the classroom. To help teachers implement the activities in their classrooms written guides were provided, as well as the laboratory equipment necessary for the activities (if unavailable at their schools), the computer simulation and instructions on how to use it. Teachers were also informed about how to carry out the activities in their classes, to allow as much as possible for a guided inquiry pedagogical approach, including details about how they should present the activities to their students and how to distribute the activity guide during the lesson.

The implementation of "Hands-on" activities involved the use of laboratory equipment. When conducting the experiment, students can measure the mass (with a beam balance) and the weight (with a dynamometer) for different objects, to find out if there is any relationship between mass and weight (see Appendix A for a more detailed description of the three tasks in the activity guide for each class).

The computer simulation "Weight and Mass" was created by our team using the *Modellus* software (Neves et al., 2013; Teodoro, 2000). The computer simulation addressed situations that may not be experienced directly by students, such as measuring the mass and the weight of an object on the moon and on other planets. Such situations are imagined through being observed in media and in movies, and attract students' curiosity and prepare them for learning about weight and mass. Although also interesting, weightlessness (Galili, 1995; Galili and Lehavi, 2003; Tural et al., 2010) was not considered because this situation is not addressed in the 7th grade official Portuguese curriculum.

The computer simulation used in this research was designed taking into account the alternative ideas of students about the concepts of weight and mass, which are associated to weight-mass confusion. For students the concepts of weight and mass are both understood as one concept, that of weight, whereas the expression "quantity of matter" is clearly related with the concept of mass. For students weight is an inherent and invariant feature of any object (Galili, 2001). When exploring the simulation, students can choose a certain value for the mass of an object and observe the different weight values of the same object on different planets (Earth, Mercury and Jupiter were used, because they are familiar to students, but any other astronomic objects are possible) and on the moon and, simultaneously, they could see the weight vector representation in each of these planets (see Figure 2).

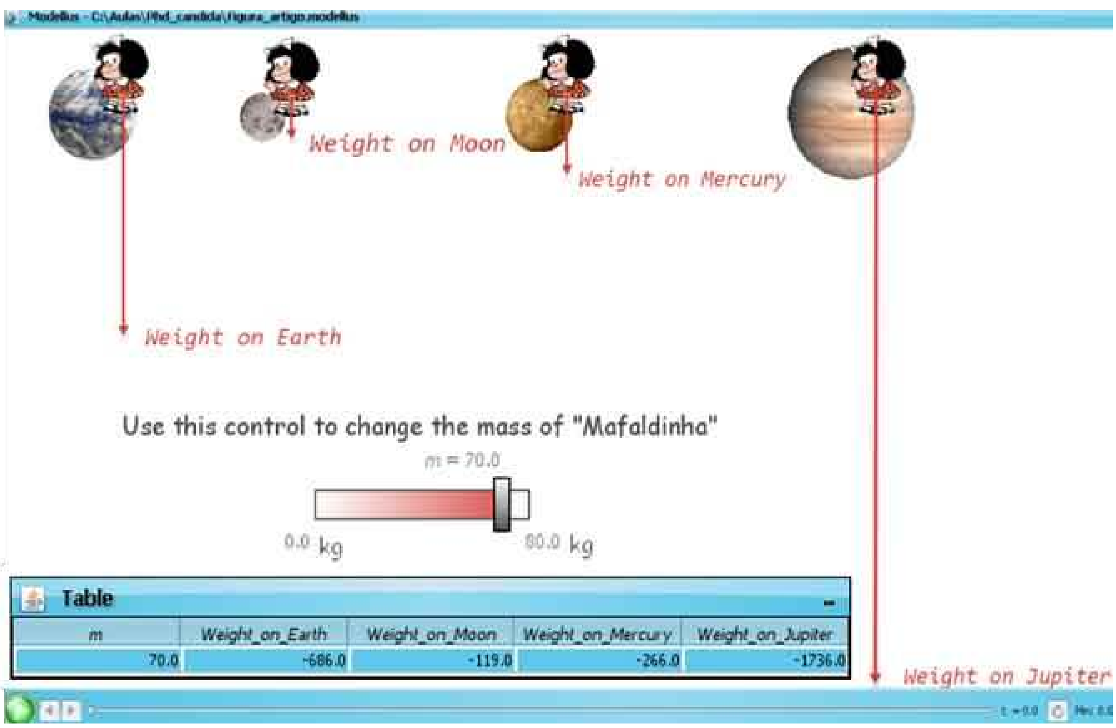

Figure 2: Screenshot of the computer simulation "Weight and Mass".

ISSN 1648–3898

With this computer simulation students could choose a value of the mass of the subject and see the weight (both value and vector representation) on earth and on other planets. With this computer simulation, students could visualize weight values and mass values of a body on earth and on other planets, which is impracticable on the laboratory school. The computer simulation, by allowing students to explore and test predictions, can also facilitate the development of students´ scientific understandings about the concepts of weight and mass.

To assess students' learning about the concepts of weight and mass, tests were administered: a pre-test (before the intervention) and a post-test (after the intervention). The post-test questions (the same used in the pre-test) were integrated among other questions in a regular formal assessment test. The test was developed by our team and refined after the pilot study. The pre-test and post-test were both composed of the same two questions. The first question (Q1) asked if mass and weight have: (a) The same physical meaning; (b) Different physical meaning. The second question (Q2) asked when a body is transported from Earth to the Moon: (a) its weight and its mass not change; (b) its weight and its mass change; (c) The weight changes and its mass does not; (d) its weight stays the same and its mass changes. In both questions students also had to justify their answer.

These questions were formulated based on the concepts of weight and mass, which are integrated in the official Portuguese curriculum of Physical and Chemical Sciences for the 7th grade ("Earth in Space"). As mentioned before, this curriculum requires the gravitational definition of weight ("the gravitational attraction force that a planet exerts in a body") and the theoretical definition of mass ("quantity of matter").

Thus, validated answers for question Q1 should include knowledge that mass and weight have different physical meaning because mass is the quantity of matter and weight is the gravitational attraction force that a planet exerts in a body. For question Q2, validated answers should include knowledge that weight changes and that mass does not because mass does not change from place to place, but weight changes because gravity in the moon is different.

Data Analysis

Answers of the students that answered both tests (pre-test and post-test) were analyzed according to the criteria shown in Table 2 (based on Gönen, 2008). These criteria were applied to the justification that students provided in their answers. The answers given by students in the tests were analyzed independently by three researchers, obtaining in all cases an agreement exceeding 95.0% (the average was 98.6%). In all situations where there was disagreement in the classification of the responses, the discrepancy was only of one level.

Table 2. Criteria used to describe the conceptual understandings.

Level	Criteria
3	Answer that includes all the components of the validated answer
2	Answer that shows some understanding of the concepts
1	Answer incorrect or irrelevant, illogical, or an answer that is not clear, or blank answer

The answers given by the students for questions Q1 and Q2 were analyzed simultaneously, first in the pre-test, and then in the post-test, to see how many responses there are of: i) level 3 in both Q1 and Q2 (Very High Comprehension – VH); ii) level 3 in one of the questions and level 2 in the other question (High Comprehension – H); iii) level 2 in both Q1 and Q2, or level 3 in one of the questions and level 1 in the other question (Low Comprehension – L); iv) level 2 in one of the questions and level 1 in the other question or level 1 in both Q1 and Q2 (Very Low Comprehension – VL).

These values were used in the nonparametric statistical analysis performed in the research.

Data about teaching were collected through semi-structured interviews, with teachers participating in the research, to try to gather information about how they conducted their lessons (Appendix B). The interviews lasted an average of 30 minutes and were analyzed through content analysis guided by the dimensions shown previously in the introduction (section "Teachers' role in student learning with computer simulations").

Results of Research

Students' Learning about Weight and Mass

Table 3 provides a summary of pre-test and post-test results for students of teachers A, B and C, when students' responses to questions Q1 and Q2 are analyzed simultaneously.

Table 3. Frequencies in percentage for the different types of comprehension about weight and mass (pre-test and post-test) and corresponding number of students.

Teacher	Class	N	Pre-test (Level of Comprehension)				Post-test (Level of Comprehension)			
			VL	L	H	VH	VL	L	H	VH
A	HoA	25	84.0 (21)	16.0 (4)	0.0 (0)	0.0 (0)	64.0 (16)	8.0 (2)	16.0 (4)	12.0 (3)
	HoA+CS	27	88.9 (24)	3.7 (1)	7.4 (2)	0.0 (0)	48.1 (13)	25.9 (7)	22.2 (6)	3.7 (1)
D	HoA	27	100.0 (27)	0.0 (0)	0.0 (0)	0.0 (0)	70.4 (19)	29.6 (8)	0.0 (0)	0.0 (0)
	CS	24	100.0 (24)	0.0 (0)	0.0 (0)	0.0 (0)	41.7 (10)	29.2 (7)	16.7 (4)	12.5 (3)
E	HoA	19	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	63.2 (12)	21.1 (4)	10.5 (2)	5.3 (1)
	CS	20	100.0 (20)	0.0 (0)	0.0 (0)	0.0 (0)	55.0 (11)	40.0 (8)	5.0 (1)	0.0 (0)

A Wilcoxon test was used to determine whether there was a significant difference among the treatment groups in terms of change in their content knowledge from pre to post-test, for Q1 and Q2. Results showed a statistical significant change in conceptual understanding from pre-test to post-test for all groups of all the three teachers: Teacher A – class HoA ($Z=-2.762$, $p=0.006$) and class HoA+CS ($Z=-3.153$, $p=0.002$); Teacher B – class HoA ($Z=-2.828$, $p=0.005$) and class CS ($Z=-3.354$, $p=0.001$); Teacher C – class HoA ($Z=-2.414$, $p=0.016$) and class CS ($Z=-2.887$, $p=0.004$).

A Mann-Whitney U-Test was used to determine whether there was a significant difference among treatment groups of each teacher, in terms of their content knowledge of the concepts weight and mass (Q1 and Q2). The differences in groups' content knowledge were not statistically significant ($p > 0.05$) before the lesson about weight and mass (teacher A: $U=325$, $n1=25$, $n2=27$, $p=0.699$; teacher B: $U=324$, $n1=27$, $n2=24$, $p=1.000$; teacher C: $U=190$, $n1=19$, $n2=20$, $p=1.000$). Likewise, after the lesson about weight and mass, there was no significant difference among groups of teacher A ($U=308.5$, $n1=25$, $n2=27$, $p=0.556$) and of teacher C ($U=185$, $n1=19$, $n2=20$, $p=0.872$). However, there was a statistically significant difference ($p < 0.05$) among groups of teacher B in terms of their content knowledge of the concepts weight and mass after the lesson of weight and mass ($U=203$, $n1=27$, $n2=24$, $p=0.010$).

A Kruskal-Wallis test also was used to compare the three HoA classes (from teachers A, B and C), and to compare the three classes with CS (from teachers A, B and C). Pretest results were compared first to see whether the groups were equivalent at the beginning of the study. The differences in groups' content knowledge of the concepts weight and mass were not statistically significant before the lesson about weight and mass among the groups in class with CS ($H=5.031$, $p=0.081$). However, there was a statistically significant difference among groups in class HoA ($H=7.690$, $p=0.021$). The Kruskall-Wallis test tells us only that there is or is not a statistically significant difference, not where the difference lies. To find out where the difference lies we used the LSD method of Fisher. This test indicated that students of teacher A, in class HoA, obtained higher classifications in the pre-test. After this lesson, there was no significant difference among groups in class HoA ($H=1.341$, $p=0.511$) and between groups in class with CS ($H=2.280$, $p=0.320$), in terms of their content knowledge of the concepts weight and mass.

Table 4 provides the total gains, G(%) = %post-%pre, for students of teachers A, B and C. These gains were calculated considering changes to higher levels of understanding, that is excluding answers of level 1 in both Q1 and Q2 (answers stay incorrect or irrelevant) and also answers of level 2 in one of the questions and level 1 in the other question ($G_T=G_{VH}+G_H+G_L$).

From Table 4 we can see that the total gains (G_T) were higher for students who used the computer simulation, from all teachers. This result is not very surprising and confirms previous findings, e.g., a recent review by Rutten et al. (2012). Comparative studies indicate that traditional instruction may be successfully enhanced by using computer simulations. In most cases, the use of simulation leads to improvements in learning outcomes and the use of the simulation "Weight and Mass" did help students learn the physics concepts of weight and mass.

Table 4. Total gains (G_T) for students of teachers A, B and C.

Teacher	Class		GT (%)
A	Class HoA	(N=25)	20.0
	Class HoA+CS	(N=27)	40.7
B	Class HoA	(N=27)	29.6
	Class CS	(N=24)	58.4
C	Class HoA	(N=19)	36.9
	Class CS	(N=20)	45.0

Role of Teachers

Analyzing the interviews to the three teachers participating in this research through content analysis guided by the dimensions shown previously in the introduction (Teachers' Role in Student Learning with Computer Simulations), it was possible to identify some of the characteristics of these teachers' mediation when using computer simulations.

Table 5 summarizes the result of this analysis, by dimensions of the mediation of each of the teachers when their students used the computer simulation, alone or integrated with "Hands-on" experimental activities. There are common features in the mediation of teachers, but there are also distinct aspects that may explain the different gains achieved by students.

Table 5. Characteristics of the teachers' role when students used the computer simulation.

Dimension	Teacher		
	A	B	C
A1	- Proposed tasks by reading aloud - Made sure that students under-stood and performed the tasks	- Proposed tasks by reading aloud - Made sure that students under-stood and performed the tasks	- Proposed tasks by reading aloud - Made sure that students under-stood and performed the tasks
A2	- Task 2 was based on a real context - Tasks 1 and 3 were not based on a real context	- Tasks 1 and 2 were based on a real context - Task 3 was not based on a real context	- Tasks 1 and 2 were based on a real context - Task 3 was not based on a real context
A3	- Reviews the concepts taught in the previous class, which are linked to the concepts of weight and mass - Proposed tasks, reading aloud - Orally explains the mode of operation of the measuring apparatus and simulation - At the end does an oral and written synthesis , and students copy it to their notebooks	- Reviews the concepts taught in the previous class, which are linked to the concepts of weight and mass - Proposed tasks, reading aloud - Gives students time to try first to address, in groups, the problem issues - Explains the mode of operation of the simulation projecting it on the interactive whiteboard for whole class - Makes an oral synthesis at the end of the 1st class and makes an oral and writing synthesis in 2nd class, and students copy it to their notebooks	- Proposed tasks, reading aloud - Orally explains the mode of operation of the simulation - Didn't do any synthesis at the end of lesson (would be made later). Students copy to their notebooks a synthesis prepared by a col-league
A4	- Information sources: script, measurement devices, simulation, teacher	- Information sources: script, simulation projected on the interactive whiteboard, teacher	- Information sources: script, simulation, teacher

Dimension	Teacher		
	A	B	C
A5	- Helps students to confirm or infer their ideas or procedures, in each group	- Helps students to confirm or infer their ideas or procedures, projecting for all the simulation on the interactive whiteboard	- Helps students to confirm or infer their ideas or procedures, in each group
B1	- Uses an interactive and dialogical discourse, with a scientifically correct language	- Uses an interactive and dialogical discourse, with a scientifically correct language (several occasions of teacher / class interaction)	- Uses an interactive and dialogical discourse, with a scientifically correct language
B2	- Provides the necessary resources to carry out the tasks - Creates an environment where students can discuss - Students worked in small groups, having been given them time and autonomy - Guides students	- Provides the necessary resources to carry out the tasks - Creates an environment where students can discuss - Students worked in small groups, having been given them time and autonomy. Gives students more time to try to address the problem issues - Guides students (projects the simulation)	- Provides the necessary resources to carry out the tasks - Creates an environment where students can discuss - Students worked in small groups, having been given them time and autonomy - Guides students
B3	- Paid attention to the involvement of students	- Paid attention to the involvement of students	- Paid attention to the involvement of students
B4	- Evaluates and gives feedback to students - Did synthesis at the end of the lesson	- Evaluates and gives feedback to students - Made several syntheses	- Evaluates and gives feedback to students - Didn't do any synthesis
B5	- Did not propose any task after the completion of the script tasks	- Proposed the resolution of manual exercises on weight and mass concepts	- Did not propose any task after the completion of the script tasks

Discussion

Based on the information gathered from the interviews to teachers, this discussion addresses only the findings associated with statistical significant results referred in the previous section, which can be summarized as follows:

1. There is a statistically significant change in conceptual understanding of the concepts weight and mass from pre-test to post-test for all groups of all the three teachers. The total gains were higher for students who used the computer simulation (alone or combined with "Hands-on" activities). However, there is no significant difference between them (CS and HoA+CS).
2. There is a statistically significant difference between groups of teacher B in terms of their content knowledge after the lesson of weight and mass. Students of teacher B, in the class that used the computer simulation, obtained better gains.

Finding 1 mentioned earlier indicates that prior to the different treatments most students presented scientifically incorrect conceptions about the concepts of weight and mass.

The statistically significant gains obtained for all groups of all the three teachers may be explained because the learning activities are well structured (HoA, HoA+CS or CS) and by the mediating role of teachers in the classroom:

- all the teachers explained how to use the laboratorial equipment (beam balances and dynamometers) and the computer simulation in the beginning of the lesson about weight and mass and provided a written guide for the activities;
- all the teachers helped students in the interpretation of the questions presented in the guide. When students had difficulties in answering to the problem questions the teachers referred to the computer simulation (class with CS) or to tables given in the activities guide (class HoA), to verify their ideas;
- all teachers tried to promote discussion (among students and between the students and the teacher), questioned and helped students to relate physical phenomena with representations, and to predict what was going to happen;
- all teachers used correct scientific language when talking with students about the concepts of weight and mass.

The two questions of the tests were related with the tasks of the activities guide that students had to perform. The

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first question (Q1) of both tests, related with task 3, is a question with a more theoretical approach (different physical meaning of weight and mass), but Q2 (what happens to the weight and mass of a body when it is transported from Earth to the Moon) involved the exploration of a physical situation, based on a real context (astronaut in the Moon) that was inferable directly from the computer simulation (Task 2 in the activities guide). All students in class with CS (HoA+CS or CS only), from teachers A, B and C, tried to answer this task (Task 2) using only the computer simulation.

Students manipulating the computer simulation visualize information in ways that students using laboratory equipment cannot see. When they were using the computer simulation, they could see a table with the values of the weight of a body in three planets (Earth, Mercury and Jupiter) and in the moon and, simultaneously, they could see the weight vector representation in each of these planets (see Figure 2). For instance, when they changed the mass value of the character, they could see what would happen to the weight of her body in each of the planets (vector representation in the planet and respective value in the table).

The statistically significant difference, after the lesson of weight and mass, between students in class HoA and students in class with CS, of teacher B, i.e., finding 2 mentioned earlier, suggests that the total gains obtained for students in class with CS may be related to the use of the computer simulation but also to the teachers' role when using the computer simulation to teach the concepts of weight and mass.

Apparently, the use of the computer simulation helped students' learn the physics concepts of weight and mass. However, students of teacher B in class with CS obtained the highest gains, corresponding to a better comprehension of the concepts of weight and mass.

Teachers participating in this research (A, B and C) used the same computer simulation and the same guide for the students' activities. But, from the interviews to teachers, is noticeable that teacher B certainly guided students in different ways, which may explain the different learning gains obtained in class with CS.

Teachers A and C explained verbally how students could change the value of the mass in the simulation, but teacher B projected the computer simulation, therefore providing a more visual explanation: *"I projected [the computer simulation] in the interactive whiteboard and showed how to change the mass value in the simulation".*

All teachers reported giving time and autonomy to students to perform the tasks proposed in the activities guide, and created an environment, where students could discuss and present their ideas to each other. However, from the interviews it is noticeable that teacher B provided more time to find the answer to each question, and encouraged students to think for themselves: *"Before to do the task, students tried to answer the problem question proposed in the beginning of the task".*

All teachers tried to promote discussion (among students, when using the computer simulation and between the students and the teacher), questioned and helped students to relate physical phenomena with representations, and to predict what was going to happen. Teachers A and C did this by going to each group of students, but teacher B used the projection of his own computer screen when providing help and support, therefore allowing the entire class to follow the discussions.

Teacher B involved students through oral questioning and requesting contributions, which engage and challenge students. In the end of the lesson, students of teacher B wrote the main conclusions (all the answers to the questions for each task on the activity guide) in their notebooks. This may explain the higher gains obtained by students of teacher B in class with CS, who used only the computer simulation to do all the tasks of the activity guide.

Teacher B also integrated the computer simulation with other practical activities so as to support sequential knowledge building, consolidation and application, like pencil and paper problem solving: *"… next we solved exercises about mass and weight".*

These strategies, of integrating computer simulations with pencil and paper problem solving, present great potential for students' learning (Concari et al., 2006). A characteristic of successful use of computer simulations is that they provide opportunities for students to reflect upon and reconstruct their original conceptions (Klahr et al., 2007; Lin and Lehman, 1999). Prompting students to explain and justify their actions and findings promotes conceptual understanding (Lin and Lehman, 1999). In the present research, the higher gains obtained in the class with CS of teacher B (using only the CS) may be related to the multiple opportunities for students to reflect on their conceptions about weight and mass, and the time and autonomy given to students to find their own answers.

According to Hennessy and colleagues (2005), the teacher´s critical role in shaping classroom discourse and establishing norms for active student participation may include developing a stronger culture of sharing ideas, reflections and procedures, with working partners and during whole-class instructional conversation. Teacher B promoted, more than the other teachers, this kind of discussion and the students were asked several times about their ideas on weight and mass.

A critical aspect of the successful use of computer simulations is providing high-quality support structures (including training on how to use the computer simulation), scaffolding and feedback about decisions and actions. Support structures should strengthen the connection between target science content and the computer simulation, as well as encourage critical thinking (Trundle and Bell, 2010). The groups that used the computer simulation experienced the same support structure, namely in the form of a common guide for the activities. However, as reported, teachers used different ways for providing support and feedback, with teacher B using visual information to complement speech and creating more opportunities to reflect and reconstruct the students' understandings of the concepts of weight and mass.

From interviews to the teachers, our results suggest that it is extremely important to provide students with a learning environment in which an adequate balance is established between the support that is given to students and the freedom that students have to accomplish tasks in the classroom (Rutten et al., 2012). In a similar way, Gonzalez-Cruz, Rodriguez-Sotres and Rodriguez-Penagos (2003) suggest that offering students some freedom while they use the computer simulation is more beneficial, as long as the teacher still reviews and comments on their work. They recommended a strategy where both freedom and structure are offered, which is in line with research on the ineffectiveness of minimally guided instruction (Kirschner et al., 2006). In general, this research also confirmed that it was very important to give time and autonomy for students to explore the computer simulation, where they can see, at the same time, the value of the mass of a body, the respective value of the weight, and the weight vector representation on the different planets. This visualization allowed students to distinguish the two concepts (mass as a scalar quantity that is conserved; weight as a vector quantity that is different in each planet of the solar system). On the other hand, the support given by teachers to students during the exploration of the computer simulation was also very important, through reviews and comments on their work.

According to Hennessy and colleagues (2007), using computer simulations effectively in science teaching is not as straightforward as it first appears. Science teachers need to undergo complex and interrelated processes of subject, pedagogical, technological, curricular and contextual knowledge transformation in order to teach successfully through simulation software. The teachers involved in this research had different subject, pedagogical, technological, curricular and contextual knowledge. In fact, despite being informed about the aims of the research, and all aspects to be considered during the implementation with students in the classroom, the differences are clear between the three teachers in terms of how they conducted their lessons in the classroom. But the differences extend to the preparation of the lessons. For instance, teachers A and B prepared all the material necessary for students to perform the experimental activities (beam balances, dynamometers, different masses, and computers with the computer simulation already installed, for each group of students). Students of teacher C, in class with CS, had to bring the computers to the classroom in the beginning of the lesson and then the teacher installed the computer simulation in each of the computers, causing unnecessary disruption of the activities.

The results obtained show that to make computer simulations effective, several aspects must be interconnected: the available resources; the tasks for students; and the mediating role of the teacher in the learning tasks, which is in line with Hennessy and colleagues (2005).

Also from the results obtained, the following important characteristics of teacher pedagogy emerged that may enhance students' learning about the concepts of weight and mass, when using a computer simulation:

providing high-quality support structures (for example, in the form of an activity guide) and including training on how to use the computer simulation;

- providing visual explanations to complement verbal explanations is particularly important when using computer simulations that are inherently visual (students could see the difference between the concept of weight (vector) and mass (scalar);
- providing enough time for students to find their own answers and encouraging them to think for themselves and share ideas among them, about the concepts of weight and mass;
- involving students through oral questioning and requesting contributions, which engage and challenge students to think about the two concepts;
- making sure that students write the main conclusions, that allow them to distinguish the concept of weight and mass, after the experimental activities;
- integrating the computer simulation with other activities (like pencil and paper problem solving) so as to support sequential knowledge building, consolidation and application, based on the concepts of weight and mass;
- providing scaffolding and feedback about students' decisions and actions, when exploring the computer simulation.

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These results emphasize the close connection between the efficacy of computer simulations and the pedagogy through which they are implemented. Learning results were better when teachers assured that students understood the tasks they had to perform and the goals of such tasks, and promoted discussion among students and between the students and the teacher. The findings suggest that the structure of the activity, the resources supplied to students (activity guides or other forms of guiding documents) and the balance between support and autonomy given to students during the activity are fundamental to ensure learning of the concepts of weight and mass.

Conclusions

The results show that there is a statistically significant change in conceptual understanding of the concepts weight and mass for all groups of all the teachers participating in this investigation. However, the total gains were higher for students who used the computer simulation (either alone or combined with "Hands-on" activities) and the highest total gains were obtained by students who used only the computer simulation. This was a surprise since we anticipated that the computer simulation used together with "Hands-on" activities would be more effective, but the use of only the computer simulation proved more effective. This probably happens because students who used only the computer simulation had more time to explore it, whereas those who also engaged in "Hands-on" activities had less time to interact with the computer simulation (in both cases the total lesson time was 90 minutes, but the students who did not conduct the "Hands-on" activities spent more time using the computer simulation). Nevertheless, even a very simple computer simulation (such as the one built and used in this research) affords opportunities for considerably better understanding of the concepts of mass and weight. This approach was used in the strict boundaries imposed by the official Portuguese school curriculum, showing that even under such constraints the use of a computer simulation helps students develop significantly better conceptual understanding of two concepts that are considered historically difficult.

From the differences found in this research results it is possible to infer that the teacher has a very important role when using computer simulations to improve students' learning about the concepts of weight and mass, including:

- Develop learning activities that are well structured and sequenced, and offer students authentic tasks, allowing students to distinguish the two concepts;
- Making sure that students understand what is asked from them in the proposed tasks and actually perform those same tasks;
- Guiding students in experimenting, formulating hypotheses and predictions, and critically reflecting on the results, comparing them with the answers given to questions and situations addressed in the computer simulation, through the multiple representations that it affords.

The implication of this research for educators and educational researchers is that even a very simple computer simulation can improve students' understanding about the concepts of weight and mass. Also, the most important characteristics of teacher pedagogy that may improve students' learning about the concepts of weight and mass, when using a computer simulation, were related with the balance between support and autonomy given to students during the experimental activity.

Despite high expectations for computer simulations, we cannot guarantee an overall conclusion about its effectiveness. Computer simulations provide new affordances for learning, particularly when they are based on phenomena that cannot easily be observed and explored in the real world. However, teachers have a crucial role in planning the learning experiences of their students using simulations and in promoting their learning through appropriate pedagogy.

Furthermore, it is plausible to suggest that, in order to make effective use of computer simulations environments, teachers need to believe not only that the affordances of these environments can support their students' learning, but also that they have themselves a crucial role in planning and managing the learning experiences, so that affordances match students' learning needs and students are able to perceive and use these.

It should be noted that the results from the empirical research are based on just one topic (the concepts of weight and mass) and a single computer simulation, with a maximum of 90 minutes allotted for the interaction of students with the computer simulation. Generalizing the results of this research to other topics requires additional research.

Further research studies are necessary to understand better which characteristics of teacher pedagogy that may contribute (and how) to improve students' learning of physical sciences when using computer simulations.

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Appendix A. The three tasks proposed in the activity guide in each class

Task 1. Students had to find the relationship between weight and mass of a body.

Class HoA	Class HoA+CS	Class CS
- Students determine experimentally the mass of various objects, using a beam balance and record the measured values in a table. - Students determine experimentally the weight of the objects previously used, using a dynamometer, and record the measured values in a table. - Students calculate the quotient (weight/mass), for each of the objects and record the calculated values in a table. - Students find the relationship between weight and mass of an object. - Each student finds the value of his or her own weight on Earth.	- Students determine experimentally the mass of various objects, using a beam balance and record the measured values in a table. - Students determine experimentally the weight of the objects previously used, using a dynamometer, and record the measured values in a table. - Students calculate the quotient (weight/mass), for each of the objects and record the calculated values in a table. - Students find the relationship between weight and mass of an object. - Each student finds the value of his or her own weight on Earth.	- Students select one value for the mass (40 kg) of the object and verify the correspondent value for the weight of the object on Earth and record both values in a table. - Students select different values for the mass of the object and check the correspondent values for the weight of the object on Earth, recording the pairs of values in a table. - Students calculate the quotient (weight/mass), for each case and record the calculated values in a table. - Students find the relationship between weight and mass of an object. - Each student finds the value of his or her own weight on Earth.

Task 2. Students had to explain how the weight of a body relates to the mass of the planet where it is.

Class HoA	Class HoA+CS	Class CS
- Students observe a table with the values obtained for the weight of a object (mass 1 kg) in different planets and the tabulated values for the mass of the planets compared to the mass of the Earth. - Students are asked if the mass and weight of the object varies, when the body changes of planet. - Students are asked how the weight of an object varies with the mass of the planet where it is. - Students are asked what would happen to the weight and mass values of the object if it was taken from Earth to the Moon.	- Students select a value for the mass, in the CS, and observe the correspondent value of the weight of the object in different planets of the solar system and record these values. - Students are asked if the mass and weight of the object varies, when the body changes of planet. - Students observe the CS and a table with the values for the mass of the planets compared to the mass of the Earth, and are asked how the weight of an object varies with the mass of the planet where it is. - Students are asked what would happen to the weight and mass values of the object if it was taken from Earth to the Moon.	- Students select a value for the mass, in the CS, and observe the correspondent value of the weight of the object in different planets of the solar system and record these values. - Students are asked if the mass and weight of the object varies, when the body changes of planet. - Students observe the CS and a table with the values for the mass of the planets compared to the mass of the Earth, and are asked how the weight of an object varies with the mass of the planet where it is. - Students are asked what would happen to the weight and mass values of the object if it was taken from Earth to the Moon.

Task 3. Students had to identify the main differences between the concepts of weight and mass.

Class HoA	Class HoA+CS	Class CS
- Students had to answer the following questions for both mass and weight: What is it? Measuring instrument? S.I. unit? Scalar or vector quantity? Does it vary from planet to planet?	- Students had to answer the following questions for both mass and weight: What is it? Measuring instrument? S.I. unit? Scalar or vector quantity? Does it vary from planet to planet?	- Students had to answer the following questions for both mass and weight: What is it? Measuring instrument? S.I. unit? Scalar or vector quantity? Does it vary from planet to planet?

Appendix B. Post-lesson semi-structured interview to teachers

Note: Before beginning the interview, the purpose of the interview is explained to participants (what the findings will be used for) and they are informed of the procedures/layout relating to the interview.

At the beginning of the lesson:

- Did you provide an overview of the topics taught in the previous lesson?
- Did you draw schemes in the whiteboard? Did you show a PowerPoint presentation?
- Did you ask questions to the students? Which questions?
- Did the students answer the questions? What did they answer?
- How was the task proposed?
- Did you clarify the goals of the task?

During the lesson:

- Did all the students work in groups of 2 or 3?
- How were the activity guides distributed? One page at a time?
- Did you draw schemes in the whiteboard? Did you show a PowerPoint presentation?
- Did you ask questions to the students? Which questions?
- Did the students answer the questions? What did they answer?
- Did the students show any difficulties in exploring the computer simulation? Which difficulties? How did you notice that? (Only for groups of students who used the computer simulation)
- Did the students show any difficulties in carrying out the hands-on activities? Which difficulties? How did you notice that? (Only for groups of students who performed "Hands-on" activities)
- Did the students ask questions? What kind of questions?
- What kind of help did you provide to students?
- Did students interact among them? How?
- Did the students feel motivated? How did you realize that?
- How did you consider the performance of each task finalized?

At the end of the lesson:

- How did you consider the activities finalized?
- Did you provide an overview of the topics taught in this lesson?
- Did you draw schemes in the whiteboard? Did you show a PowerPoint presentation?
- Did you ask questions to the students? Which questions?
- Did the students answer the questions? What did they answer?
- At the end of the lesson, did you make a summary of the responses that students reached to the problem-questions? How?

Received: *January 11, 2016* Accepted: *February 26, 2016*

Cândida Sarabando	MSc., PhD Student at the University of Trás-os-Montes and Alto Douro, Quinta dos Prados, 5000-801 Vila Real, Portugal. E-mail: candidasarabando@hotmail.com
José P. Cravino *(Corresponding author)*	PhD in Physics Education Research, Assistant Professor at the University of Trás-os-Montes and Alto Douro, Quinta dos Prados, 5000-801 Vila Real, Portugal. Researcher at Research Centre "Didactics and Technology in Education of Trainers", Aveiro, Portugal. E-mail: jcravino@utad.pt
Armando A. Soares	PhD in Physics, Assistant Professor at the University of Trás-os-Montes and Alto Douro, Quinta dos Prados, 5000-801 Vila Real, Portugal. Researcher at INEGI/Faculdade de Engenharia, Universidade do Porto, Porto, Portugal. E-mail: asoares@utad.pt