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## In-Service Education of Science Teachers: Virtual Simulators as a Resource for Experimental Work

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### Abstract

This article presents a 50 hour course for in-service science teachers who wish to conduct experimental work with their students using the potentialities of the Information and Communication Technologies (ICT). This course was designed taking into consideration that several studies in Portugal have shown that in-service science teachers still have lots of difficulties in setting experimental work in a coherent pedagogical framework and also that teachers don't know how to use ICT resources under a socio-constructivist learning approach. The course aims to help teachers on how to choose virtual simulators that are adequate to certain learning objectives and how to create learner-centred activities using these resources under the main pedagogical guidelines of experimental work.

### Key words

In-service education of science teachers; Experimental work; Virtual simulators.

## Formación Continua de los profesores de Ciencias: simuladores virtuales como un recurso para el trabajo Experimental

### Resumen

Este artículo presenta un curso de 50 horas para profesores de Ciencias en servicio que desean realizar trabajo experimental con los alumnos utilizando las potencialidades de las Tecnologías de la Información y Comunicación (TIC). Este curso fue diseñado teniendo en cuenta que varios estudios en Portugal han demostrado que profesores de Ciencias en servicio tienen dificultades en la creación de trabajo experimental en un modelo

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pedagógico coherente. Se ha evidenciado también que los docentes no saben utilizar los recursos digitales bajo un enfoque de aprendizaje socio-constructivista. El curso pretende ayudar a los profesores sobre como elegir simuladores virtuales que son adecuados para ciertos objetivos de aprendizaje y desarrollar actividades centradas en el alumno utilizando estos recursos bajo los principales lineamientos pedagógicos de lo trabajo experimental.

### **Palabras clave**

Formación continua de los profesores de Ciencias; Trabajo experimental; Simuladores virtuales.

## **Introduction**

This article presents a 50h course for in-service teachers, “Virtual Simulators in the Experimental Work in Sciences”, designed for teachers of the 1st, 2<sup>nd</sup> and 3<sup>rd</sup> cycles of the Portuguese Basic Education system. It is framed under the national teacher’s continuous education programme and it aims at implementing experimental didactical-pedagogical practices, using virtual simulators in the classroom.

Therefore, this article begins by contextualizing the objectives of the Science Teacher’s Continuous Education, as well as its legal framework. Next, the relevant aspects concerning Virtual Simulators and Experimental Work are presented. Finally, the designed course is presented and an example of a work session is given.

## **In-Service Education of Science Teachers in Portugal**

In the report “Science Education NOW: A Renewed Pedagogy for the Future of Europe” presented by Rocard et al. (2007) the concern on the improvement of the student’s scientific education is clear, emphasising the role of the teacher and his/her training as essential to that improvement:

*Improvements in science education should be brought about through the new forms of pedagogy: The introduction of the inquiry-based approaches in schools and the development of teachers’ networks should actively be promoted and supported. Teachers must remain the key players in the process of reform, but need better support that complements professional training and stimulates morale and motivation. (Rocard et al., 2007, p. 17).*

Concerning the Portuguese legislation, Teacher Continuous Education is ruled by Decree-Law n.º 22/2014, of 11 of February. It foresees the enhancement of the teacher’s professional development by investing in continuous education courses, improve the quality of the teaching practices and hence of educational success. Furthermore, the continuous education priorities should be properly identified by the schools and this identification should be the basis to conceive specially designed courses taking into account the results of the evaluation of schools and the training needs of teachers.

In line with this it should be noted that, as Vieira (2003) and Marques (2004) reported, there hasn’t been a large number of training activities in Science Education or relevant impact in terms of didactic and pedagogical practices. There is a lack of motivation of teachers and a shortage of materials / resources, which are seen as inherent factors in this demotivation. However, these are not the only factors that should be pointed out, as the didactic and pedagogical practices of teachers focus too much on the transmission of knowledge

instead of scientific capabilities and attitudes (Santos, 2007; Reis, 2008; Vieira et al, 2011; Reis, 2013). In this sense, the teaching of sciences has been focused on memorization of concepts, while it is highly recommended that, concerning teaching science: “[The report recommends that] teaching should concentrate more on scientific concepts and methods rather than on retaining information only and that stronger support should be given to teacher training in science.” (Rocard et al., 2007, p. 8).

In this line of thought, it is important to highlight the role of Continuous Teacher Education as a necessary response for the development of scientific literacy of students, namely through experimental work practices by teachers in their classrooms (Martins, 2002; Vieira, 2003; Mamede and Zimmerman, 2005; Reis Rodrigues & Santos, 2006; Madaleno, 2010).

Another aspect to consider is that Continuous Teacher Education should be based on the teacher's experience in training and in his/her conceptions about science teaching-learning and the science they teach (Correia, 2007), offering a training environment of social-constructivist nature, based on reflections with and between teachers and trainer (Lucas and Vasconcelos, 2005; Reis, 2010; Torres, 2012). So, a Continuous Training Program for Teachers should not make a “clean sweep “of ideas, practices, contexts and difficulties of teachers, bearing in mind that:

*The way we teach science has to do with how one conceives the science he/she taughts and how it is thought that the other learns what is taught (well more than the mastery of methods and teaching techniques), making relevant deepening further aspects with a view to epistemological training of teachers (Cachapuz, Praia & Jorge, 2002, p. 55).*

In the context of this article, and for the design of continuous teacher training course presented here, we took into account the Science Professor Cognitive Domains, presented by Carlsen (1999) (Fig.1).

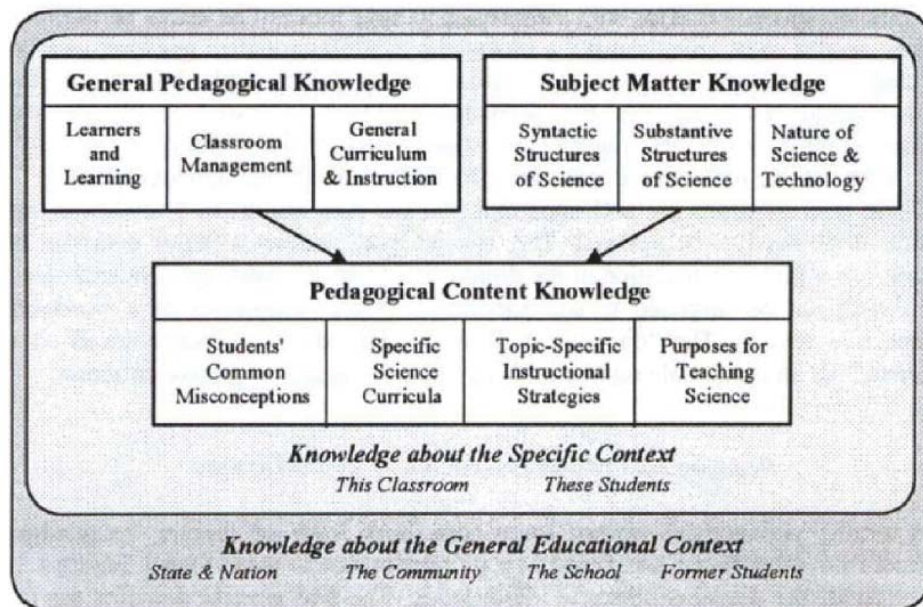


Figure 1. Domains of teacher knowledge (Carlsen, 1999, p. 136)

Carlsen (1999) presents five domains that should be considered for the professional development of the science teacher, what the training should take into consideration in the

design phase, and that can be identified in Figure 1. Of these, we highlighted the Pedagogical Content Knowledge, as it is the knowledge that allows the selection of strategies by the teacher that seem most appropriate to him, taking into account, for example, materials / resources to be used, such as the simulators.

In addition to the aspects listed above, we highlight the importance of teacher reflection on their conceptions and on their practices (Alarcão, 2001) as an essential dimension in a continuous training program, as it promotes a framed professional knowledge in an "attitude of permanent questioning - of itself and its practices "(Alarcão and Roldão, 2009, p. 30).

## Virtual Simulators

### Definition and characteristics

Currently teachers have a wide variety of computer applications for the teaching and learning of sciences. Jimoyiannis & Komis (2001)'s systematization, based on several authors, emphasises spreadsheets, computer-based laboratories, multimedia, simulations, exploratory environments and intelligent tutors. We believe this systematization is important as it will allow a better comprehension on the use of simulators by teachers and some errors concerning their pedagogical use. We should also have in mind that it is not easy to find consensual definitions on educational software categories, since an educational software usually falls under several different of those categories. Still, a definition is needed as we need to make sure that we and the teachers in-training are "speaking the same language".

In this course, we use the de Jong & van Joolingen (1998) definition of simulation-based learning as computerized environments where learning takes place by the learners as they interact with the entities of the environment and gradually infer the features of the concept model which may lead to changes in their original concept. We like this definition for a course on science education as it puts an emphasis on two different models – the initial learner's mental model on a scientific subject and the "scientific" conceptual model of the subject. Indeed, "*Research on physics and science education has often focused on the study of alternative conceptions and mental representations that students employ before and after instruction. Related to the above is research focused on the study of the consequences of special teaching interventions aiming to transform students' alternative conceptions.*" Jimoyiannis & Komis (2001). This definition also implies that a computer model was intentionally created to represent characteristics, behaviours or processes of a system – ideally the ones that are the learning objectives of the lesson. A *model* is always a simplification of a real system, usually done to enhance learning – keeping the students focused on what matters (De Jong et al., 1998). Still, the teacher can opt for more complex, high-fidelity models as learning takes place, but this is always chosen strategically from the pedagogical point of view.

Virtual simulators are computerized environments and thus the learner interacts with a computer model. Computer models are built upon the mathematical models of the phenomena or system to be studied. Learners can interact with the model by changing the values of the input variables (causes) and see the outcomes in the output variables (effects). Fig. 2 shows an example of a computer simulator on density: students may change two input (independent) variables, mass and volume, and see the effect on an output (dependent) variable (density). The simulator also allows, as an input variable, the type of material of the body (ex: wood).

Recchi, Gagliardi, Grimellini, and Levrini (2006, cit. Psycharis, 2011) argue that well designed computer simulations help the learner to explore, predict actions and results, evaluate ideas and enter deep cognitive processes as critical thinking. Still, we can ask how well a computer simulation “per se” can help the learners, without a guided teacher orientation (example: without knowing previously the alternative conceptions students have on the topic). As we will see in the following sections, we put a strong emphasis on the activity that is set by the teachers and how to design a learner centred activity under the socio-constructivist theories.

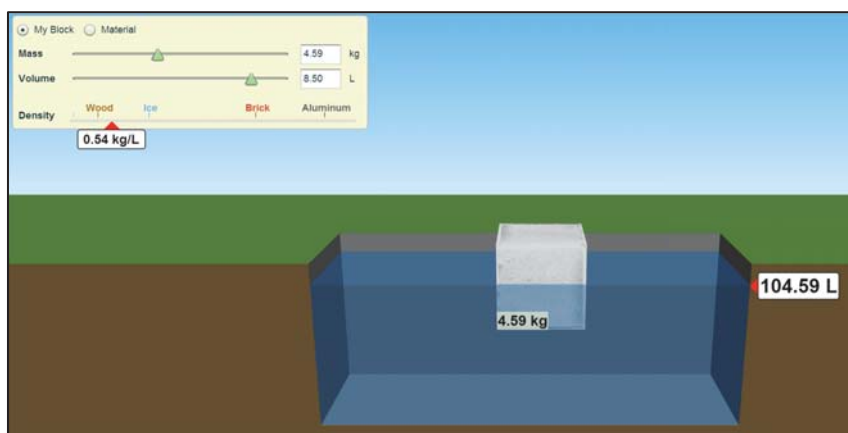


Figure 2. Density simulator (available at <https://phet.colorado.edu/en/simulation/density>)

### Advantages and disadvantages

Most of the advantages of using simulators in the classrooms are well known, as offering practical “hands-on” experiences that would be impossible (ex: gravity in space), dangerous (ex: volcanos), expensive, needing specialized equipment or travel. Also, they offer an enhanced visualization technique: “Visualizations may be especially useful for helping students see structure in phenomena and processes that are traditionally “invisible” to students. A process can be invisible if it is too small (bacterial reproduction), too big (tectonic shifting), too fast (chemical reactions), or too slow (evolution)” (Lindgren & Schwartz, 2009). Still, simulators also have disadvantages when compared with other learning methods. Lunce (2006) systematized some studies that evidenced the following:

- They require more time than many other methods of instruction;
- They require that teachers give appropriate coaching, scaffolding feedback and debriefing, reflection (or the learners gain little from the discovery learning simulations can facilitate - sometimes learners tend to interact with a simulation as if it was a game);
- They oversimplify real life, giving the learner imprecise understandings.

### Teacher’s Misconceptions on the use of virtual simulators

In our course for in-service teachers, we will begin by asking teachers about their definition of what a simulator is. From our experience, some concepts will emerge that are not according to our definition. First, some teachers consider simulators as physical (or material) models like the physical mannequins used in medical and nurse training or physical flight simulators used in the military forces. Although these are, in fact, truly

educational simulators, they are not virtual (computer-based.) In this course we will emphasize the virtual simulators as they are generally cheaper (most of them are free) and more accessible to students (we can have one per student, if the classroom has enough tablets or laptops). Second, some teachers mistake realistic 3D models (either physical or virtual) as simulators, as, for example, the 3D model of the human skeleton. According to our definition, this would constitute a model of a system but not a simulator of a system as the learner doesn't interact with it to change his/her mental models on a phenomena. As mentioned, most definitions of learning simulators tend to focus on the aspect that learners learn by interacting with the model (Alessi & Trollip, 2001). Therefore, although 3D models are rich learning resources, these will not be the scope of our course.

Although simulators are extremely adequate for a constructivist learning, by allowing students to ask “what would happen if...?” questions and test them in real time, the use of simulators alone is not sufficient to say that a constructivist learning is taking place. Even today some teachers use them “in the wrong way”, not fully embracing all their pedagogical advantages.

One of the most common errors on the use of simulators in classroom is that teachers assume the control and interaction with the simulator, showing the students the causes and effects (Lindgren, & Schwartz, 2009). This has obviously pedagogical limitations as the teacher is subtracting the experimental potential of these educational resources. In one particular aspect of this approach, a teacher can use a screen capture software to produce a movie where he/she uses the simulator, narrating it to expose the learning objectives, and sharing it with their students in a video sharing platform like YouTube. Fig 3-a shows a video on the issue of “density” using the density simulator referred above. Although this has interesting pedagogical benefits – the flipped classroom strategy for example – it is even more limited in a constructivist scenario as it cannot generate from the alternative conceptions of the students. Also, some teachers use this approach just to create a *machimina* – a movie animation produced by setting the input variables conveniently. Fig 3-b shows an animation on “ship motion and wave simulation” where input parameters were chosen (as the ship position, scale, sea characteristics, etc.) to make an educational video for teaching a specific learning objective. Such resources belong, of course, under the “multimedia” computer applications as categorized by Jimoyiannis & Komis (2001).



Figure 3. YouTube videos concerning a) Density; b) ship motion and wave simulation (from <https://www.youtube.com/watch?v=HTUc9w7aL8A> and [https://www.youtube.com/watch?v=7aojVJJA\\_b4](https://www.youtube.com/watch?v=7aojVJJA_b4) respectively)

## Experimental Work

In Portugal and many other western countries practical activities of experimental nature have a main role in the curricular guidelines of the Ministry of Education. Therefore, more

than scientific knowledge, it is important the development of competencies taking into account the way science is done. Capacities and attitudes in sciences are an example (Afonso, 2005; Vieira & Tenreiro-Vieira, 2005). In this sense, it is important that practical activities of experimental nature help children to explain and comprehend the world that surrounds them, to question and research their ideas, developing their own research process (Martins *et al.*, 2006).

Therefore, practical activities are those that promote an active implication of the student during the implementation of the activity (Leite, 2001) and it is considered a quality strategy in science education. Yet, Millar (2010) also refers that “as practised in many countries, it is ill-conceived, confused and unproductive” (p. 176), which justifies the teacher’s continuous training in this regard.

Practical-Experimental activities are those where there is the manipulation of variables and it is studied how the independent variable influences the dependent variable, taking into account controlled variables. This type of work potentiates the intellectual and socio-affective development of the child (Afonso, 2005), promoting a scientific and technological education for all (Ibarra, Arlegui & Wilhelmi, 2009).

## Course Design

### Objectives, contents and evaluation

The course “Virtual Simulators in the Experimental Work in Sciences”, aimed at teachers from the 1<sup>st</sup> to the 3<sup>rd</sup> cycles of the Basic Education System has the following objectives:

- a) Mobilize teachers to develop innovative practices in the teaching of sciences in their schools;
- b) Identify, explore and analyse simulators according to the students and learning goals;
- c) Explore didactic contexts of experimental work using simulators;
- d) To plan experimental work activities using simulators as a resource;
- e) Build resources/materials that will support the experimental activities using simulators;
- f) Reflect on the course’s training path and its impact in the teacher practices.

This will be a 50 hour course, being that 25 h are in-class and 25 h of autonomous work. We list below the course structure, contents and chronogram:

1. Framework of the course (1:00 h)
2. Experimental teaching of sciences : (5:00 h)
  - 2.1. Practical, laboratorial and experimental work
  - 2.2. Experimental work in the Basic and Secondary Curricula
  - 2.3. Experimental teaching practices of science in the classroom
3. Simulators and Learning (3:00 h)
  - 3.1. Definition, Types, Characteristics
  - 3.2. Interactivity and variable manipulation

- 3.3. Feedback mechanisms
4. Simulators in the Experimental Teaching of Science (6:00 h)
  - 4.1. Searching and Exploring different educational simulators
  - 4.2. Analysis of simulators as educational resources (potentialities and limitations)
  - 4.3. Presentation of simulators (identifying potentialities and limitations)
5. Planning activities for the use of simulators in the classroom (3:00 h)
6. Building support materials for the use of simulators in the classroom (3:00h)
7. Evaluation of the activities – reflexion, analysis and group discussion (4:00h)

As can be seen by the course structure and contents, theory and practice coexist in a logic of virtual simulator analysis, planning and running classes using simulators as a resource as well as the conception of materials/resources for students through the use of simulators. In all these situations, the reflexive dimension of the teacher will always be present so that teachers question their conceptions and reflect on their didactic-pedagogical practices.

The hours of autonomous work (25h) were planned taking into account the needs of the teachers-trainees as they will have several tasks to implement, concerning planning and execution of a class using simulators as a resource by the students. The course trainers will be available to guide the teacher-trainees, helping and supporting them, giving feedbacks about the work for its improvement.

At the end of the course the teachers-trainees will have to deliver and present a written work that will include:

- a) The planning of an experimental work in a classroom scenario, using a simulator
- b) Justify the pertinence of the selected simulator
- c) Possible materials/resources to be used in that class
- d) Reflexion on how the class was conducted
- a) A reflexion on the impact of this course in the personal, professional and social development of the teacher-trainee

### Methodology of a course session

The course will address several scientific areas (astronomy, biology, physics, chemistry, etc.) and will explore several educational simulators. An emphasis will be put on the conception of activities for the simulator's exploration in a socio-constructivist perspective.

We will describe in detail a work session with the teachers. We will use as an example the simulator illustrated in fig. 4. The scientific area is "astronomy" and the topic "The Lunar Phases".

1. We will begin asking the several teachers how they currently approach the topic "The Lunar Phases". Teachers may debate among themselves on the benefits and limitations of their current strategies.
2. We will then present them the simulator illustrated in fig. 4 and ask them to explore it. We may guide them, asking them to identify all the variables that can be manipulated with the simulator and identify those that are linked to the specific learning objectives. These are the input (independent) variables. This simulator, for instance, allows the manipulation of two variables, the earth rotation movement



and the moon translation movement (as seen from the earth). Teachers must also identify the output (or dependent) variables. In this simulator, the output/outcome of the manipulation of the input variables is a visual representation of the moon (as seen from an observer from the earth – i.e. the moon phases) and the sun and moon positions in the sky (from the point of view of an observer looking at the horizon line). The identification of the independent and dependent variables allows the identification of causes and effects.

3. Then, we will ask the teachers to identify all the learning objectives on the topic (taking into consideration the school year) that can be properly addressed by that simulator and those which cannot.
4. Teachers will then be asked to develop a strategy/activity on the use of the simulator, which will later be presented and discussed with the other teachers. We will look to put the teacher in a reflection attitude: how does the activity promote the development of scientific processes (observation, prediction, variable control, etc.) The teacher should also reflect on how much the activity is learner-centred and how it leads to cognitive conflict. For this purpose, teachers should first know (ask) the learner's ideas, to identify possible alternative conceptions and orient learners to construct meaning from the unexpected results obtained.
5. Finally, teachers can discuss on the advantages and disadvantages of the new learned “virtual simulator approach” particularly confronted with the “common” physical educational simulator that most of them use (a globe, in a dark room, with a source of light pointed at). For example, what other variables can be/ cannot be manipulated (ex: distance of the light source) and its implications (ex: light rays become more parallel between themselves)

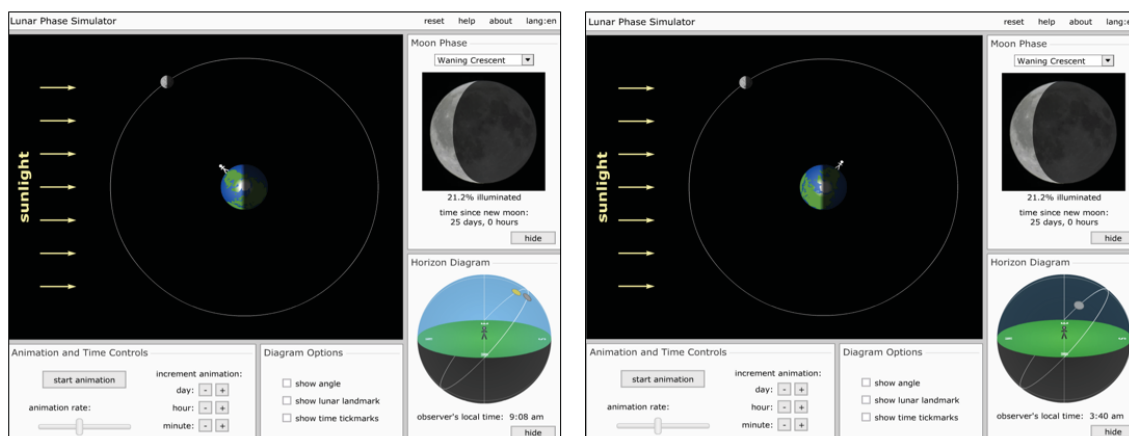


Figure 4. Does the rotation of the earth affect the moon phase? Lunar Phase Simulator available at <http://astro.unl.edu/naap/lps/animations/lps.swf>.

## Final remarks

Current didactic views on the teaching and learning of sciences support practical classes based on experimental work. This is not always possible, as many schools still don't have the necessary equipment, but, more important, many teachers fail on how to use this didactic view productively. Also, ICT may address some of the shortfalls of the specificities of laboratorial work, as simulators often offer good models with which students can

interact too. Still, teachers also seem to fail to use them under a socio-constructivist framework. These facts made the course proposed in this article relevant and current.

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