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A Microworld for laboratory lessons in physics

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Abstract
This paper presents the conception of a Microworld designed for learning physics and the pilot study of its use in the classroom. The observations from the classroom activities show that students do not question the way the Microworld represents reality, even where the tool is limited to a simplified physics. From this finding, we discuss the knowledge embodied in the tool and the way it can be used for fostering a deeper understanding of physics.

Introduction
This paper presents the conception of an ICT tool called "Marbles Move" and the pilot study of its use in the classroom. It is a Microworld (for a definition, see Kynigos, 2007) designed for laboratory lessons in physics at the high school level. The conception of the tool and the pilot study in the classroom takes place in the European Funded Project ESCALATE[1].

One of the main objectives of the European project ESCALATE was the implementation of argumentation and inquiry based ICT tools in genuine learning contexts. The aim was both to design environment fostering inquiry and argumentation among peers, and to provide a documented follow up of the introduction of these tools in the everyday teaching practices. The main idea for designing and using Microworld was to improve the learning environment in providing students more opportunities to engage personally into inductive learning processes such as knowledge co-construction.

The activities of experimentation and collaboration were also meant to nourish peer-discussion and argumentation allowing students to confront their viewpoints and their understanding of the situation. The reason ESCALATE chose to support argumentation is related to the fact, well documented in science education, that learners have their own ideas about physical phenomena, usually called "preconceptions" or "misconceptions". The important differences between these preconceptions and the physics as a culturally shared

[1] ESCALATE (*Enhancing Science Appeal in Learning through Argumentative interaction*) is a project co-funded by the European Commission within the Sixth Framework Programme (2002-2006) – project number: 020790 (SAS6). For further details: http://www.escalate.org.il.

body of knowledge is known at least since piagetian studies about children reasoning (Inhelder & Piaget, 1955). These preconceptions are very resistant to formal teaching (Driver, Guesne, & Tiberghien, 1985), in particular when science is understood and/or taught as a dogmatic body of knowledge (Driver, Leach, Millar, & Scott, 1996). Argumentative discussions were considered as likely to help this learning (Muller Mirza & Perret-Clermont, 2009; B. Schwarz & Glassner, 2003; B. Schwarz, Neuman, & Biezuner, 2000; B. B. Schwarz, Neuman, Gil, & Ilya, 2003).

In the curriculum and in many teachers' practice, the knowledge to be taught is simplified. For instance, Viennot (1989) identifies a general tendency to reduce the reasoning in mechanics to a single variable, and to reduce the various notions to their numeric expression. The general consequence of this problem is that physics teaching might make students able to pass tests to demonstrate their progression within educational system, but the majority of students still base their reasoning on preconceptions when they need to make a qualitative judgment about a problem in the physical world, or more generally when they need to use their knowledge of physics to interpret the physical world in their everyday life.

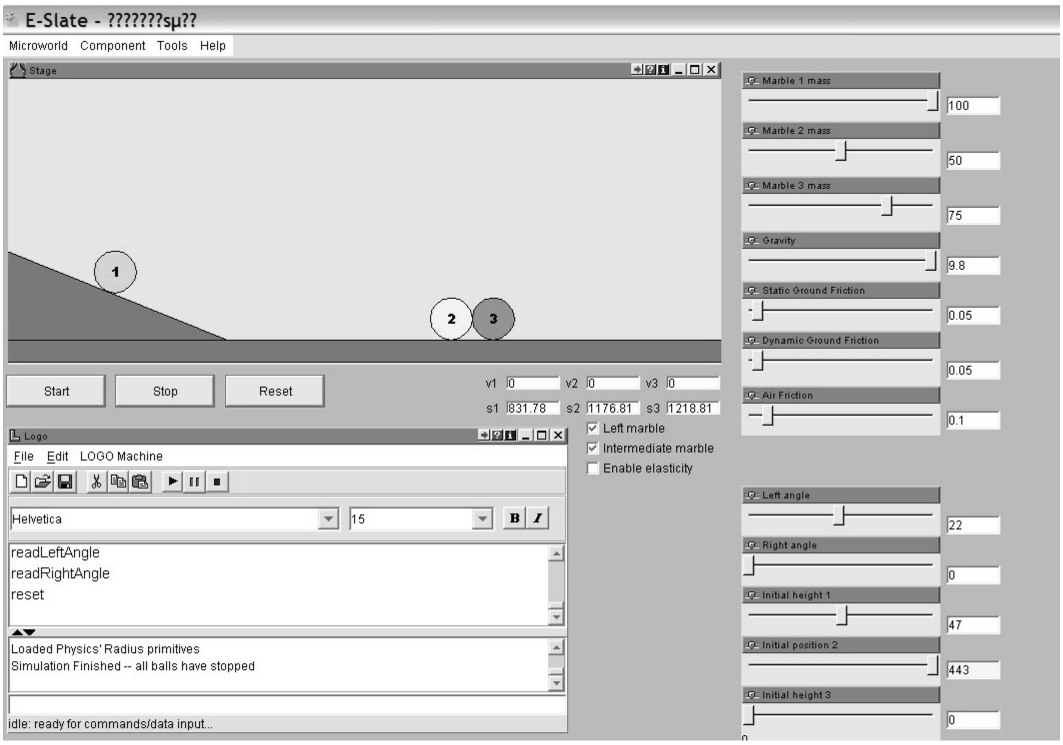
Marbles Move

The Microworld "Marbles Move" that A. Kohler has designed is inspired from two piagetian tasks. The first consists in laying a set of marbles ordered in a row on a flat surface, and leaving one marble to roll down a slope in such a way that it will hit the first marble of the row. In Piaget's experiment (Piaget, 1974), the apparatus is explained to the child without performing the demonstration, and the experimenter asks the child to predict what will happen. Children usually think that the whole row of marbles will move. The child is later allowed to try, and the experimenter asks him why only one marble moves. Piaget has designed this task to interview children about their understanding of causality. Children were resistant to imagine a transmission of movement through the immobile marbles. Indeed, if the rolling marble follows a perfect run, when it hits the row only the last marble at the other end of the row will move, while all the other marbles will stay still. Newtonian concept of inertia provides an explanation to this rather strange phenomenon. Alternatively, analyzing the moment of the shock between the marbles with the Newtonian concept of force can also provide an explanation, which entails to understand that forces applied on a body are not always oriented identically to the movement of the body. A known preconception about Newton's third law (see Lemeignan & Weil-Barais, 1993) is precisely that students usually draw forces on a body only when it moves, and directed alike the movement.

A similar task has been used by Piaget in another experiment (Piaget & Garcia, 1971), in order to study children's notion of force. This second task consists in presenting the child with a track in which marbles can only roll straightforward. The track is concave on both sides, in such a way that a marble rolling from one end goes up the opposite slope and down again, and so on. The experimenter asks the child to predict the height a marble would reach on the slope when it is starting at different heights on the opposite slope. The track also allows children to set different angles for the slopes. The notion of force approached here is merely referring to the force applied by gravity on the marbles, and its consequences on the marbles acceleration and velocity. Therefore, successful predictions in this task do not implicate yet that children understand that in Newton's physics forces may apply on a still object, or may apply on a moving object but in a different direction than the movement itself.

The pedagogical intentions behind the choice of these two tasks was to provide high school students with a physical setting where they could inquire about two topics of Newtonian physics related to well-documented preconceptions: the concept of inertia, and the concept of force. Finally, the Microworld was designed to include the following characteristics:

- The Microworld would represent marbles moving on a straightforward trajectory in a simulation window.
- In the simulation window the movement represented would be performed through an algorithm that takes into consideration as many variables as possible: angle of slope,



distance, gravity, diverse frictions, elasticity of the shock … The idea here is to program a Microworld that does not over simplify the physical situation.

- Next to the simulation window would stand an interface where all variables involved in the calculation can be set to the desired value, within a range of values relevant for the visualization in the simulation windows. This maximal controllability aims at making the Microworld a rich environment for inquiry.

The Microworld was thought as a possibility to explore Newtonian laws qualitatively through an intuitive change of variable, and systematically through the clear distinction between those variables, and to provide students with a direct visualization of the effect on the simulation window. This pedagogical intention was online with ESCALATE intention of enhancing learning via co-construction and experimentation. Figure 1 presents the interface of Marbles Move.

Figure 1. *The Microworld Marbles Move*

Design and limits

Once the Microworld sketched as mentioned above, it was presented to the computer developers. The ESCALATE technical partner programming the Microworld needed precise information about the mathematics underlying the marbles movement. In order to provide the developer with an equation, A. Kohler interviewed a physicist. The equation had to fulfill several constraints: it needed to be simple enough to be processed by the program language used to built the Microworld (to avoid efficiency problems as delay or jumps in the displayed movements), to include all variables open to students inquiry set by the researcher, to visually simulate the event in the best possible way, and to correspond to the knowledge to be taught as set in the school curriculum. The physicist offered the researcher a relevant and rich mathematical equation to manage the movement of the marbles in the Microworld as a one dimensional trajectory. This equation includes the effect of marbles masses, ground friction with two factors (dynamic and static), air friction, gravity, marbles height on the slope, and the marbles positions in the trajectory.

Creating the Microworld needed the construction of a formal expression of the physics represented by it. For instance, due to the limits of the software capability (E-SLATE plateform), the loss of velocity of the marbles where a slope makes an angle with the horizontal ground could no be included into the equation. Neither could the rotational momentum of the marbles be taken into account, nor any other physics about the rolling of the marbles. As a matter of fact, the marbles were eventually treated by the Microworld as if they were slipping on the surface, and not rolling at all.

Pilot study

Once the first version of the Microworld ready, A Kohler contacted a physics teacher in a local high school to set up a pilot study. It took place at the end of the school year, within laboratory lessons that could not be used for working on the curriculum, due to the fact all the semester marks were already given. The activity brought by a researcher external to the college was therefore probably perceived as an entertaining activity. This context of implementation fitted well with the objective of this first pilot study. The idea was, at this point of the project, to leave students use Marbles Move freely. To direct their attention on the topic, the activity started with a questionnaire asking questions similar to Piaget's studies with children. After having given their guesses, students were put in three different conditions: one group could use the Microworld and real material, another group only the material and the third group only the Microworld. They could check their first guesses in groups with the avalaible tools.

From this pilot study, two observations are particularly relevant to the question of the implementation of the tool into an everyday classroom activity. First, leaving the students free with the Microworld without framing exercises or activity was very rich in terms of discussion and oral reasoning, but each group developed their experimentation about different aspects of the situation (e.g. gravity, momentum, forces applied on the marbles, inertia, rotational movement and rotational inertia). As a consequence, it was more difficult for the teacher to make the usual "closure" of the activity with a final analysis of the groups' contributions. The activity resulted in a lack of conclusive statements about the different issues discussed.

Second, students having both the Microworld and the real material usually preferred to rely on the Microworld data for performing experiments. The reason for this choice is still unexplained. More importantly, only one student noticed and discussed explicitly the discrepancies between the observation of the real material and the simulation on the Microworld. This student called the teacher, and through a dialogue with him came to understand that the real marble rolling down the slope stops for a very short moment, almost not perceptible, and then starts rolling again as an effect of the rotational inertia. In the Microworld the rotation being not included in the algorithm, the marble stays perfectly still after the shock with a row of immobile marbles of the exact same weight.

Observations in the everyday laboratory lessons

After the pilot study, Marbles Move was implemented in a classroom within a teaching sequence of one semester. In order to match curriculum teaching objectives, instruction sheets and exercises were provided to guide students' activities with the tool. Students were working collaboratively on one exercise sheet in groups of three or four for one computer. At the end of the semester an assessment of students' understanding was made via a paper pencil test triggering preconceptions. In the final assessments, students having worked with the Microworld did better than students of the same grade in the same high school. The percentage of right answers at the questionnaire was better than documented in the literature about the specific preconceptions involved (Courtillot & Ruffenach, 2006; Lemeignan & Weil-Barais, 1993). We can therefore make the hypothesis that the tool together with other elements of the teaching sequence such as the focus on argumentative discussion, made students works more in depth the knowledge presented or made them relate more the knowledge with their own ideas. In order to explore the role played by the Microworld integrated in the sequence, we present below some observations.

Students were generally motivated to use the Microworld and they did not encounter obstacles in learning how to handle it. However, they often started by exploring it in depth and by trying to use it for their own entertainment. For instance some students propelled marbles the fastest and highest possible. But even in such an instrumentalization of the tool for their own agenda, some learning of physics was involved as they had to inquire in order to discover which variables to set on which value in order to make the marbles go faster and faster.

The groups displayed good and often very good participation in the discussion, and most of them were focused on the activities. However, the moving away from these rich discussions to the activity consisting in answering the worksheet was far from being easy for learners. Often one student is in charge of playing the role of secretary for the group. This implies a loss of the richness, when it comes to record it on paper.

The observation of the phenomenon posed a real challenge for them, whether on a computer or in a material setting. Students were not used to look carefully, even less with a physicist's eye. Another difficulty for the students was to manipulate one variable at a time and observe the effects. Students considered the simulation to be a much more reliable source of information than hands-on experience, as aften used it as the unique mean for inquiry. Nobody raised doubts on the validity of the Microworld underlying model.

The Microworld does not offer a copy of reality but a model

These discrepancies between the observations of the real material and the Microworld remind us that the Microworld is not replacing the real material, but provide students with a different experience of inquiry. What is that differs? The emphasis is often put on the possibilities of manipulation that a tool offers, on its affordances (for a brief critique of the too broad usage of this concept, see Norman, 1999). Here, the Microworld provides students with the possibility of manipulating variables directly with slides displaying values on the screen. However, this is probably not the main difference between inquiry learning with the Microworld and with the real material. A more fundamental difference lays in the fact that the Microworld does not include the whole phenomenon it is supposed to refer to.

This abstraction of some aspects of the natural situation is questionable. In actual fact, it is one of the main skills of the physicist to consider only the most relevant variables of a physical situation, on which the model can be built, and to ignore others in order to be able to "read" the situation and set up an equation for calculation and prediction. The genius of

Newton was not only to bridge together separate areas of physics, but also to ignore friction and all sorts of “noise” in order to make a model that allows to calculate and predict phenomena with a very good approximation in relation to the observation of reality. As in the Microworld, these choices have already been made the model is already embodied in the Microworld, at least partly. Therefore, observing the Microworld differs from observing real material in the sense that the Microworld provides a model of the physical situation under inquiry, while the real material *is* the physical situation under inquiry.

The activity of making models and the ability of understanding what a model is in physics has been recently under investigation (Tiberghien, 1994). In this approach, teaching physics is not considered as transmitting “true statements about the Laws of Nature”, nor as making students discover the Laws of Nature hidden in Reality itself. Instead, the body of knowledge of physics is seen as containing models to make sense of the observation of natural or experimental phenomena. The notion of “model” refers here to the fact that the knowledge is somehow more synthetic, abstract, than the mere observation and therefore consists in a simplification of the physical situation under consideration. Science history brings illustrations to explain this point: even the most precise calculation based on Newtonian physics are now known as mere approximation of the measure of the phenomenon. In addition, to even prove that Newtonian physics is a model – the best approximation our culture could build up to refer to some aspects of the physical world – is only possible thanks to new instruments of measure, new theories, in brief new models.

Let us consider what the implications are of the fact a Microworld provides a model in the context of teaching Newton’s physics in a classroom. The formal teaching in a classroom can be thought as the attempt to move students’ ideas about the physical world nearer to a standard body of knowledge. The teacher is representing this culturally accepted knowledge. This knowledge to be taught might not be, and often is not, the same that the knowledge of the scientific discipline, notably because it has been taken out of its original context and set in a new one, which is in our case the educational setting (Perret-Clermont, Brun, Conne, & Schubauer-Leoni, 1982). The difference between the teachers’ physics, the physics taught at school or presented in school textbooks and the physics of the physicist has been stressed a long time ago, and eventually correspond to the fact every participant in the teaching and learning activity is likely to refer to a different model (Chevallard, 1985). Physics can be seen as a concatenation of models incorporated one into another (Halbwachs, 1975). The movement of thought that leads from observation to a model of the situation under investigation is a critical moment for learners of physics, as it is the movement from their own ideas – or preconceptions – to a more powerful model such as Newtonian’s three laws of mechanics. This movement of thought does not only include definition of concepts such as forces or inertia, but does also include abstraction from some aspects of what is observed. In traditional physics teaching, the situations used to introduce one or the other aspect of the theory tend to frame the learner by directing her attention exclusively on some variables and assuming others should not be included in the model. For teaching purposes, physical situations are usually "cleaned up" from all elements from the material world that would interfere with the demonstration of the model. If the model is about the conservation of momentum, the situation will be cleaned from variables such as the friction of the ground, the rotational momentum of the marbles, slipping effect, uneven ground, and so on, in order to be able to calculate a perfect conservation of the momentum and support Newtonian's model. Later, this model proves very useful for practical objectives such as building a bridge or traveling to the moon, even if it has neglected some aspects of the observation. However, for educational objectives it is rather useless (Garduño Rubio, 1998).

The fact that the Microworld provides a model rather than a copy of reality can be interesting for teaching. It can allow students to understand that Newton's laws are a model, a theory. However, when the Microworld is given without explicitly mentioning it is a model and what a model is and how it can allow for observations, the risk is to make the gap between the abstract world of models and the observation of the complexity of reality even bigger. Alternatively, the Microworld can be very useful to teach students what a model is, and make explicit the movement of thought they are expected to do in order to overcome their preconception to adopt Newton's abstract point of view on a physical situation.

Opening to future research

Following the Microworld Marbles Move from its design to its usage in educational activities in the classroom has drawn our attention to the importance of the various models present. The students' preconceptions, the teacher's model, the knowledge as it has been defined in the curriculum and the theory of physics written a few centuries ago are altogether present in the classroom. Within this complexity, a tool such as Marbles Move can take an important role as an intermediate level of abstraction. However, for this purpose the model underlying the Microworld should be more explicitly discussed, as it is very easily taken as the truth by students. Students were not questioning at all the knowledge embodied in the tool, and were likely to trust the Microworld simulation instead of their observation of material experiment. Having a Microworld at disposal can provide an opportunity for learners to understand the role that scientific models play in physics. It means, the learners could become more aware of how a model works to represent a natural phenomenon. They could then use the Mircoworld as one model among possible others.

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