Constructing the concept of acceleration

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Abstract
We propose an introduction to the concept of acceleration in high school using devices familiar to all students. To do this, we describe a simple experiment, and then characterize, via discussion, the physical agents capable of propelling bodies.

Keywords: Acceleration, force, motion.

Resumen
Se propone una introducción al concepto de aceleración en la escuela secundaria con el uso de dispositivos conocidos para todos los estudiantes. Para ello, se describe un experimento simple, y luego se caracteriza, a través de la discusión, los agentes físicos capaces de propulsar cuerpos.

Palabras clave: Aceleración, fuerza, movimiento.

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I. INTRODUCTION

We believe that the main goal of teaching physics is to help students assign meaning to concepts that are commonly used to represent physical quantities. This recognition should enable the student to apply those concepts in different physical situations. Let us concentrate on the concept of acceleration. Although fundamental, it is difficult for students to understand, especially because most of them are unable to associate this quantity to any phenomenon with which they are familiar with. Besides, they arrive with a set of naive conceptions, which leads them to try to fit the concept of acceleration to their own vision of reality, not necessarily corresponding to a correct interpretation of the processes under study. Physics Education research supports these claims [1, 2, 3, 4, 5, 6]. A possible solution to this problem is to teach the concept of acceleration through the study of the physical agents capable of accelerating bodies. It could be argued that this approach reduces kinematics to dynamics. However, this reduction is a very natural one. It was only during the fourteenth century that kinematics was separated from dynamics [7, 8]. Thus, if an individual learns how humanity has learnt in the past, it is reasonable to study acceleration focusing on the physical processes that can change the velocity of different bodies.

II. A SIMPLE EXPERIMENT TO CONSTRUCT THE CONCEPT OF ACCELERATION

What is the difference between a motion on a horizontal plane and a motion downhill? A person sitting on a vehicle senses quite clearly the difference if the vehicle in in uniform or accelerated motion. As an example, passengers in a bus tend to fell asleep during the stretches when it moves at a constant speed, but wake up when it brakes suddenly or accelerates in a downhill stretch. This difference will be the cornerstone in our construction of the concept of acceleration.

In order to investigate the downhill motion, we built a car track in which we placed a small (about 6 cm long) toy model car, chosen for the stability of its straight line motion. The track was made from a sheet of plywood about 220 cm long. On it we marked two lanes, one sanded and varnished to make it as smooth as possible, the other with the original rough wood surface. The middle strip was marked every 10 cm. One end of the track was elevated, and intermediate supports placed, so that the model car motion takes place on an inclined plane, and lasted at least three seconds. Figures 1 and 2 show the toy car and a part of the car track. The model car was released from the top of the track, and its subsequent motion was recorded by means of a digital camera. The resulting video was analyzed with VirtualDub, a free software originally designed to insert subtitles in movies. It can be obtained directly from http://www.virtualdub.org/. The video can be accessed directly, a window that allows us to search the file opens immediately.

FIGURA 1. A Hotwheels© toy car.

FIGURA 2. A part of the car track made of plywood.

Once loaded (by clicking on “File" and then “Open" in the menu), the video can be seen frame by frame through an interactive cursor that reacts to the mouse motion. There are 20 marks on the track equally separated by a distance of 10 cm. The time interval between two frames is 1=30 s. In this way, it is possible to construct a table with the positions occupied by the toy model car with good precision, and, with it, calculate the speed at different times. In a similar way, we can estimate the rate of change of the instantaneous velocity for suitably chosen time intervals, for example between t = 1s and t = 2s. We can then call acceleration the \variation of the speed in one second." As it is easy to see, this definition is narrow and inaccurate, and the concept of acceleration needs to be refined. However, by offering a simple definition obtained directly from an experiment, we facilitate the assignment of a meaning to this concept.

In this way we start with a particular example before discussing the more general and abstract concept [1, 2, 4]. Note that the term acceleration is proposed later in the learning process. The importance of characterizing a quantity before assigning to it a name has been stressed by several authors, see e.g. [1]. A bonus of this approach that deserves being mentioned is its potential to demonstrate to students that accelerated motion does not exist solely in textbooks, where are usually discussed in idealized situations, clearly artificial. On the contrary, they are present in the day to day life of the students. We believe that the identification of that which is studied with elements of their own experience is fundamental to achieve the engagement of the students with the learning process. However, it is natural to pose the question: What causes a motion to be accelerated? The way we deal with this question is described below.

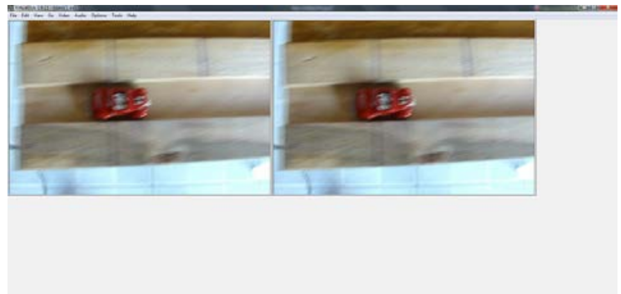

FIGURA 3. A sample of a frame taken with VirtualDub.

Let us now consider another accelerated motion, free fall. Through a strobe photo of a body in free fall [9], see Figure 4, we can discuss why this is an accelerated motion, and the magnitude of its acceleration. In that picture, the positions were taken at every 1/30s. Note also that in order to apply the method we need to know the ratio between the size of the figure, which in our case was projected on the wall, and the actual size of the system. What is the physical agent responsible for this acceleration? It is the gravitational force, a force that acts at a distance, which makes more difficult to understand its meaning. A way to help on this purpose is to compare the gravitational force with the magnetostatic force, which also acts at a distance. It can be argued, without much elaboration, that just as the presence of a magnet can make a needle move without requiring them to make physical contact, the presence of massive bodies, such as the Earth, attract smaller bodies, causing them to fall to the ground.

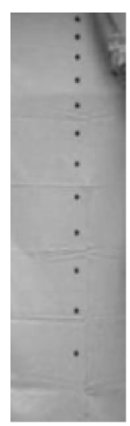

FIGURA 4. A strobe photo of a body in free fall.

III. FORCES CAUSE ACCELERATION

What makes a motion to be accelerated? Or, what agents are responsible for the acceleration of bodies? We begin the discussion considering the toy car at rest on a level surface and ask whether it will start moving by itself or not. There is a very reasonable consensus among students that the toy car can begin to move without the intervention of an external agent. After that, we take a second toy model car on which we have adapted a sail, as shown in Figure 4, place it at rest on the horizontal track, and then turn on a hair dryer towards the sail. If the car was initially at rest and then starts to move, a change in its velocity did occur, it was accelerated. What physical agent was responsible for accelerating the car? Or rather, what “new thing" in the system appeared to provoke the acceleration of the car? It is easy to see that the air blowing from the dryer is the responsible agent. The key aspect of this discussion is to make students realize that the action of a physical agent is a condition for any acceleration to take place.

A third possibility to consider is the action of a spring: we consider a spring toy car, which, after some winding and being placed at rest, accelerates when released. What is the physical agent responsible for the acceleration of the car in this case? One may take such toy car to the classroom, verify that it accelerates as described, and then disassemble it in search of the elements that produce the acceleration. In this way, we can associate the concept of acceleration to another physical agent, a spring. Is an increase in the speed the only possible effect of the action of these agents that accelerate bodies? When we push the first car, first it accelerates, but then slows down and finally comes to rest. If the model car was initially moving and then comes to rest, a change in velocity has occurred, which implies the action of another physical agent. Thus one can discuss the existence of friction and its effect on motion. Note that during this activity some interesting questions may arise, for example: Why, in a real car, do we keep pressing the accelerator pedal so that its speed remains more or less constant? If pressing the pedal accelerates the car, its speed should increase continuously, why this does not happen?

FIGURA 5. A sailing car.

Finally, we discuss the action of physical agents in motions in which velocity inversion occurs. One can observe this behavior by allowing the sailing car to roll down the inclined plane, with the hair dryer blowing uphill. In the subsequent motion, the car first accelerates, then slows down as it approaches the dryer, stops and then reverses its motion. It is interesting to discuss the acceleration at the instant of reversal. Research in physics education has shown that the belief that the acceleration is zero at the instant of rest in a motion in which there is reversal of the speed is one of the most strongly persistent in all of kinematics. We then ask the students: What is the velocity and acceleration of the car at the precisely the moment when the reversal occurs? The answer in the case of the velocity is immediate, but not so in the case of the acceleration. One can then focus attention on the physical agent that drives the inversion, the wind. It is important that students notice that throughout the motion the physical agent responsible for the slowing down and the subsequently reversal of the car motion, remains active, as evidenced by the continuous operation of the hair dryer! Thus, the continuous action of the external agent must imply the presence of acceleration during the whole motion, even at the instant of reversal. With this idea in mind, one can review the motion under the action of the Earth's gravitational force. One can compare the two motions, the car driven by the wind and the body thrown upwards driven by its own weight, and establish their similarities.

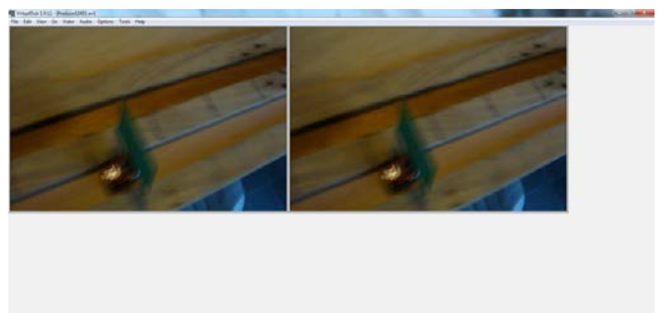

FIGURA 6. VirtualDub frame for the analysis the motion of the sailing car.

IV. FINAL REMARKS

We have presented a simple activity from which the concept of acceleration can be built. We have also discussed how that concept can be studied through physical agents that drive the bodies. The contents of this article is a fraction of a larger project developed by us within the graduate program in physics education at the Federal University of Rio de Janeiro [10, 11]. The proposal was initially applied in public schools in the state of Rio de Janeiro, Brazil. The activities, which occupied four fifty minute sections, were applied in two high school classes with about thirty students each. The activities were conducted by means of questions that directed the discussions, and took place at a pace dictated by the students, the teacher acting just a mediator. The format we chose to implement the activity is consistent with how we think that ideally the teaching process in physics should be: students must be the protagonists of their own learning.

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