NEWTON´S SECOND LAW – VIRTUAL EXPERIMENTAL ACTIVITY

Edite Pereira Briosa, *Instituto Superior de Saúde do Alto Ave, Geraz do Minho, Portugal*
Paulo Simeão Carvalho, *IFIMUP, Departamento de Física e Astronomia, Faculdade de Ciências da Universidade do Porto, Portugal*

Abstract
Virtual experimental activities have a strong positive impact on students understanding of physics. They can be designed as a complement of "real" experiments, enabling the development of fundamental skills in data reading and registering, graphic interpretation and problem solving reasoning. In this work we present a virtual experimental study about Newton's second law, as a problem solving experimental environment, based on a Physlet script by Aaron Titus, and how to explore it with students.

1. Introduction
The virtual experimental activities are designed to promote the development of skills and abilities normally associated with experimental work performed in a laboratory, for example when one is not available, when the experiment represents danger to the experimentalist or when it cannot be repeated because of time limitations. They are, preferably, a complement to real laboratory activities. They are based on Physlets, Physics Java Applets developed by Aaron Titus and Wolfgang Christian in the late nineties (Christian & Titus, 1998, Belloni & Christian, 2001, Belloni & Christian 2004). We have chosen to explore a Physlet based on Newton´s second law, transforming it in a virtual experimental activity, where a challenging problem is presented to the students: "Is it possible to measure the mass of a body without using a scale?"

2. The Virtual Experimental Activity (VEA)
The animation presented to the students is shown in fig. 1. The first part of the text describes the experimental setup that we see in the animation and provides some relevant data. An important information that the students must retain form this introductory part is that the total mass of the system does not change (controlled variable); only its distribution changes.
For a virtual activity to be profitable, it must be built in a way that allows the students to perform different trials, selecting and collecting experimental data in a table to be treated later, through the graphic method or through modeling.
In this VEA, the students must perform 4 different experiences, to be able to answer the two questions suggested in the activity and to solve, at the end, the proposed problem.
The animation already gives us the graphs for the speed of the system as a function of time, which we can enhance in size for a better view and to collect data more accurately. As an example, fig. 2 shows the graph for the third experience.
Throughout the animation, several skills must be developed by students to successfully complete every step of the activity. The first step is to calculate the acceleration in each trial, identifying the movement of the cart as uniformly accelerated, from the linear graph of as *v* vs. *t*.
For each trial, the slope of the curve gives us the value of acceleration due to the corresponding effective force (to be identified by the students as the total weight of the support – the weight of the support itself plus the weight of the discs it sustains). The values registered and calculated are shown in Table 1.

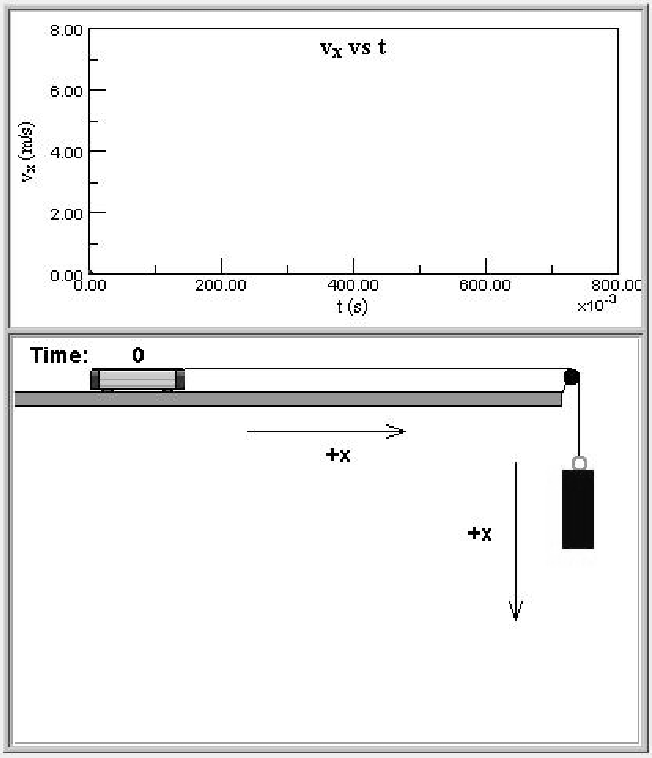
Table 1: Acceleration values for the system calculated form the slope of the curve in the respective graph ($a = \Delta v / \Delta t$), as well as the total weight of the support (force) (g = 9,8 m/s^2).

Trial	t_i (s)	t_f (s)	v_i (m/s)	v_f (m/s)	a (m/s^2)	Force (N)
1	0,04	0,78	0,13	2,55	3,27	4,9
2	0,04	0,78	0,18	3,80	4,89	7,4
3	0,04	0,78	0,25	5,10	6,55	9,8
4	0,04	0,78	0,27	6,36	8,15	12,3

Virtual Experimental Activity

"Study of the relationship between the force applied to an object and the acceleration it acquires"

Problem: how to measure the mass of a body, without using a scale?



start | pause | << step | reset | step >>

Please wait for the animation to completely load.

A cart of unknown mass is in a low-friction track. The cart is connected to a string and to a hanging blue support, of mass 0,050 kg, as shown in the animation. The cart initially carries a set of removable discs (not shown in the animation) of a total mass of 1,200 kg, that can be transferred to the blue support. Neglect any effects of the pulley on the motion of the system.

You can use the left button of the mouse to read coordinates. In this animation, the readings can be of two types: in the cart and/or in the support (position coordinates, (*x*;*y*)) and in the graphic (in this case the coordinates are (*t*;*v*)) **(position is given in meters and time is given in seconds)**. Reset

Questions to answer:

In this activity you will need to conduct a set of experiences (see below), from where you should collect data; then you will be able to build tables and graphics that will enable you to answer the following questions:

a. What is the relationship between the external force applied to the system and the acceleration of the cart?
b. What is the experimental value for the mass of the cart?

At the end, do not forget to give a solution for the problem!

Experiences to conduct:

In this activity, the total mass of the system (cart + support + removable discs) is a controlled variable, that is, it remains constant in all the virtual experiences. The removable discs, initially in the cart, can be transferred to the support. You can run the animations corresponding to the following situations:

i) Mass of removable discs in the hanging support: 0,450 kg
ii) Mass of removable discs in the hanging support: 0,700 kg
iii) Mass of removable discs in the hanging support: 0,950 kg
iv) Mass of removable discs in the hanging support: 1,200 kg

(Hint: when you get a good-looking graph, right-click on it to clone the graph and resize it for a better view)

Figure 1: Virtual Experimental Activity – Newton´s second law.

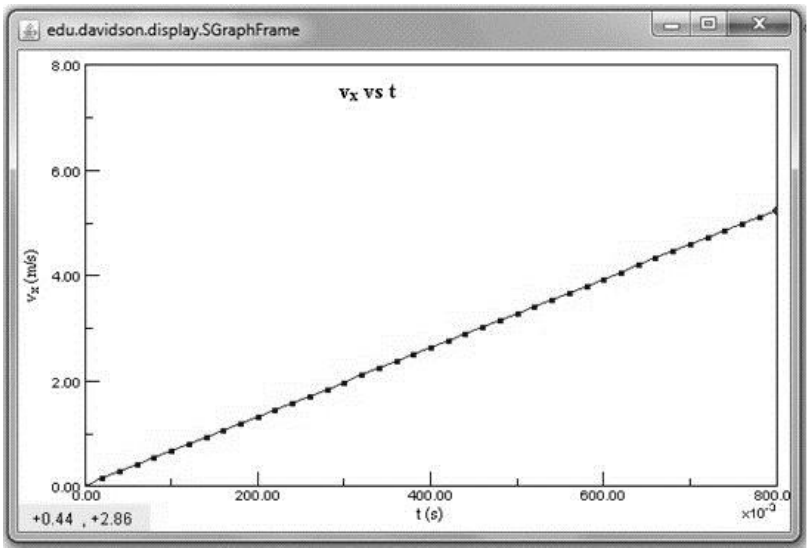


Figure 2: Virtual Experimental Activity – Newton´s second law – Graph for the 3rd trial.

A more elaborated way to determine the acceleration is through modeling. Students can register in a table the cart's position (clicking with the mouse over the cart) as time goes by and then build a graph of position as a function of time. The equation for an uniformly accelerated movement (eq. (1)) can be fitted to the collected data and the parameter a (acceleration) can be extracted from it. Figure 3 refers to the third trial.

$$x = x_0 + v_0 t + \frac{1}{2} a t^2 \tag{1}$$

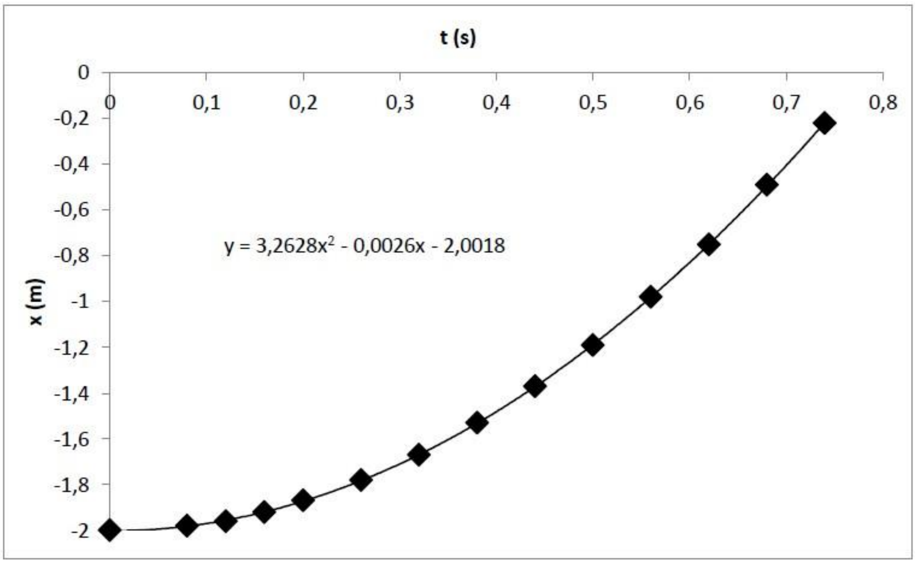


Figure 3: Graph representing the position of the cart as a function of time (3rd trial).

The acceleration values obtained from modeling are very similar to those presented on Table 1 and students should be encouraged to use modeling as an alternative and more challenging technique to work with experimental data.
We can see from table 1 that when the total mass of the support, due to the discs it sustains, is bigger, so is the external force applied and so is the value of the acceleration of the system. This observation allows the students to partially answer the first question, only by physically interpreting the results presented in the table. The identification of the type of relationship between the external force and the acceleration needs the student to build the graph that relates these two quantities.

The physical interpretation of the experimental results (figure 4) should take the students to conclude that there is a direct proportionality between the force and the acceleration, this being the first phase to the operational definition of Newton's second law.

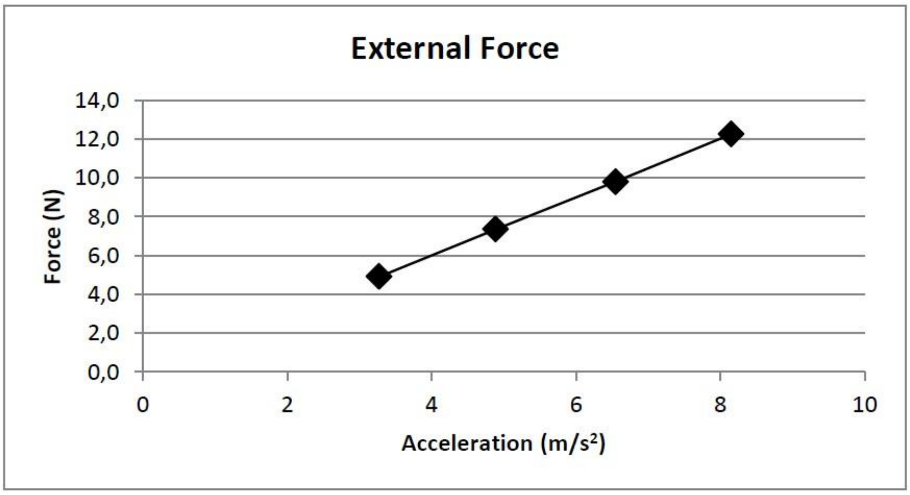


Figure 4: Graph representing the external force applied as a function of the acceleration of the system.

To completely characterize the dynamics of the system, it is of great value to draw the free body diagram, dividing the system in two parts: (a) the cart and (b) the support. In this case, and as we are only interested in the translational movement of the system, it should be discussed the use of the model of the center of mass; students will have to identify, separately, all the forces acting in each body and to represent them in the respective center of mass (figure 5), with the corresponding legend.
In the cart, the only force of interest for the motion is the tension exerted by the string (T), as this is the effective force in the direction of the movement (F_C). Nevertheless, it is important to make sure the students understand that N_C and W_C have equal absolute values, so they balance each other.
In the support, we have both the tension exerted by the string (T) and the total weight (W), ~~and~~ the vector sum of these two forces corresponding to the effective force in the direction of the movement (F_S).

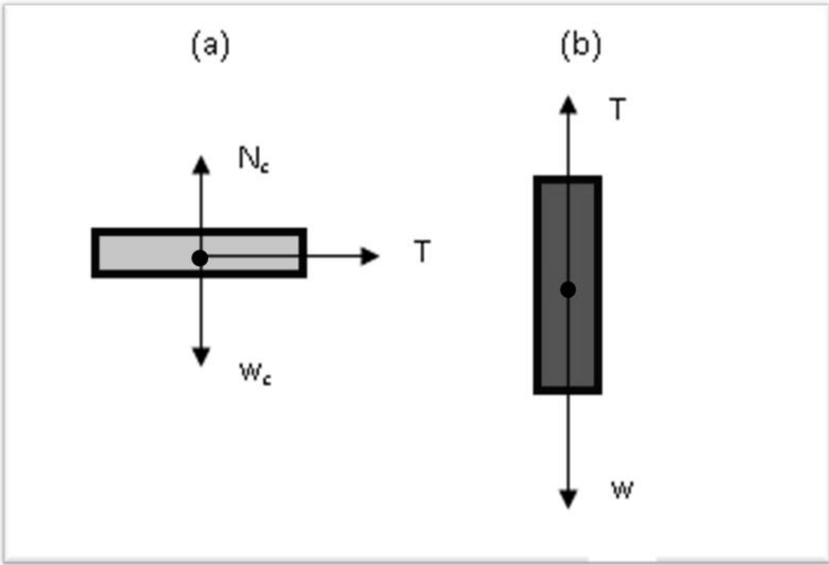


Figure 5: Free body diagram of: (a) the cart; (b) the support.

Since in the animation the positive direction is defined as the direction of the movement, we can write the equations (2) and (3) that allow us to calculate the forces in the direction of the movement for both the support and the cart. We must remember that the sum of the mass of discs in the cart (m_{Dc}) and the mass of discs in the support (m_{Ds}) is always 1,200 kg.

$$\mathrm{F_C} = \mathrm{T} = (\mathrm{m_c} + \mathrm{m_{Dc}})\ \mathrm{a} \tag{2}$$

$$F_S = W - T = (m_s + m_{Ds})\ a \tag{3}$$

From the combination of equations (2) and (3) we can obtain equation (4),

$$W = m\ a \tag{4}$$

where *W* represents the external effective force that when applied to the total mass *m* of the system, makes it move with an acceleration a.

To determine the total mass of the system, $m = m_c + m_s + m_{Dc} + m_{Ds}$, students should use the graph on figure 4 and obtain *m* from the slope of the curve, by linear fit. This method has the advantage of reducing systematic errors, what should be discussed with the students.

Table 2 summarizes the values of acceleration, effective force and the slope of the curve in the graph shown in figure 4, as well as the associated uncertainty.

Table 2: Acceleration and external force for each trial and the slope of the curve of F = f(a).

Trial	a (m/s^2)	Force (N)	Slope
1	3,27	4,9	1,503 ± 0,007
2	4,89	7,4	
3	6,55	9,8	
4	8,15	12,3	

The slope of the curve and the associated uncertainty are easily obtained through a program like Excel, using the function LINEEST. The uncertainty imposes the number of significant figures our result should have. This theme is of major importance in experimental activities, so its inclusion in this virtual activity has the advantage of discussing the subject. Uncertainties should be debated with the students in the exploration of this activity, so they will understand that even the results obtained by linear adjustment have an uncertainty associated to them that should be reported.

Since the slope indicated in table 3 corresponds to the total mass of the system, a simple subtraction gives us the mass of the cart: m_c = 0,253 ± 0,007 kg. The “real” value (inserted in the core of the VEA) is 0,250 kg.

Students can now answer to the challenging problem of the VEA: it is possible to measure the mass of a body without using a scale!

3. Conclusion

It has been shown by educational research that a more interactive approach to physics teaching has a strong positive impact in students learning (Hake, 1998). In virtual experimental activities like the one explored here, that interactivity in enhanced, giving the students a *hands on* virtual laboratory experience and the opportunity to develop fundamental skills, both in physics and in general sciences. Although VEA do not replace “real” experiments and do not develop certain procedure skills (like instrument reading, equipment manipulation and experimental setup building), they can be repeated over and over again, promoting different kinds of didactic exploration. These type of activities can also be available online, allowing students to review or explore them at any time, in any place. (http://www.fc.up.pt/pessoas/psimeao/MPTL_2011/experience_MPTL_1.html)

References

Belloni, M. and Christian, W. (2004). *Physlet Physics - Interactive Illustrations, Explorations and Problems for Introductory Physics*. New Jersey, Pearson Education.

Belloni, M. and Christian, W. (2001). *Physlets: Teaching Physics with Interactive Curricular Material*. New Jersey, Prentice Hall.

Christian, W. & Titus, A. (1998). Developing Web-based Curricula Using Java Physlets. *Computers in Physics,* Vol. 12, nº 3, pp. 227-232.

Hake, R. R. (1998) Interactive-engagement versus traditional methods: a six-thousand survey of mechanics test data for introductory physics courses. *American journal of Physics,* Vol. 66 (64-74).