

# Can Accelerators Accelerate Learning?

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**Abstract.** The 'Young Talented' education program developed by the Brazilian State Funding Agency (FAPERJ) [1] makes it possible for high-schools students from public high schools to perform activities in scientific laboratories. In the Atomic and Molecular Physics Laboratory at Federal University of Rio de Janeiro (UFRJ), the students are confronted with modern research tools like the 1.7 MV ion accelerator. Being a user-friendly machine, the accelerator is easily manageable by the students, who can perform simple hands-on activities, stimulating interest in physics, and getting the students close to modern laboratory techniques.

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## INTRODUCTION

Physics teaching, perhaps more than the teaching of any other subject, faces several challenges. The first one is that in the same way that Physics, as the main basis of nineteenth and twentieth century technologies, became strongly associated with the successes of these technologies that changed our world, it is now associated with their ecological impacts and their misuses in general. Adding to this, other Basic Sciences such as Biology, Computing and Astronomy are undergoing a tremendous growth, with also many applications, frequently associated with clean technologies and human health. In short, Physics is no longer a trendy subject and faces tough competition for the hearts and minds of the students, even the scientific-minded ones.

The second challenge is associated with the teaching approaches used during high-school. These approaches range between two extreme cases: a description of assorted physical phenomena with some mathematical formalism, associated with experimental work, or a more analytical description - Physics is a set of many laws which must be solved in practical cases - and generally with little phenomenological discussion and no experimental activities. While the former path, easy to follow in developed countries, seems to the student a stream of unrelated phenomena,

the latter one seems to the student a stream of unrelated formula. This latter approach, cheaper as does not require laboratories, is more common in middle-income and less developed countries.

The third challenge, very strong in non-rich countries, is the lack of quality of fundamental education, leading to high-school students frequently having difficulties in reading texts or in understanding mathematical abstraction.

How can one show the beauty and the basic and applied relevance of learning Physics? First, at lecture level, one should stress the many links between Physics and other Natural Sciences, showing how simple models help to understand phenomena in Chemistry, Geology, Meteorology, Oceanography, Engineering, Astronomy, Genetics, Ecology, etc, and in everyday life. Second, the more interested high-school students should have, wherever and whenever possible, contact with real experimental physicists working in their labs. This is not as hard to attain in large cities, even in middle-income countries such as Brazil.

A successful program developed between the California State University and a local high school through which the students conduct experiments using linear accelerator has been reported [2,3]. In this paper, we describe a program developed by a Brazilian State Funding Agency (FAPERJ) for high-school pupils showing interest in physics, intending to bring

them to the daily activities of researchers in universities. The students are selected from public schools in the State of Rio de Janeiro and led to take the first steps in research. The objectives are twofold: at individual level to stimulate the scientific formation of students and to identify new vocations in science; at a more general level to contribute to the diffusion of scientific knowledge, demystifying science and articulating research and teaching.

## THE PROJECT

The students are selected from public high schools in Rio de Janeiro metropolitan area. The student selection is performed by FAPERJ. The agency invites researchers, willing to accept high-school students in their institutions, to take part of the project. The researchers say how many students they can tutor and the school year the students are attending. The students can choose among the many scientific areas, the one to which they feel more attracted, such as Physics, Biology, Chemistry, etc... In our lab, we accept one or two students every six months, and the scholarship can be renewed in a six months basis. Despite of their natural interest in physics, the students involved in the program, as opposed to students from the top private schools in Brazil, lack background to do the more advanced level tasks such as those performed by the undergraduate students in the Advanced Lab course [4] at UFRJ. Then, we decided to perform experiments in which senior high-school students may become involved, in principle without introducing new physical concepts. However, due to the inherent difficulties experienced by most of public schools in Brazil, the high-school teachers barely have an opportunity to explore subjects such as electromagnetism and optics. The curriculum presents an emphasis in mechanics, more particularly in kinematics, and consequently the students lack knowledge on electromagnetism.

Considering these problems, the transport of ion beams in a particle accelerator is a very motivating tool for the pupils to be introduced to the fundamentals of electromagnetism. The experiments explore the well-known Lorentz force

$$\mathbf{F} = q(\mathbf{v} \times \mathbf{B} + \mathbf{E}), \quad (1)$$

using for this two element: the Wien filter and the magnetic selector. Also interesting is performing computing simulations of the transport of ion beams

and seeing how it is affected by these and by other elements.

## The Hands-On Activities

The accelerator is equipped with a Wien Filter. The filter can be used as a mass spectrometer or a velocity selector. It has mutually perpendicular electric and magnetic fields, both of them making also a right angle with the ion velocity. There is a specific velocity  $v$  such that the ions will feel magnetic and electric forces equal in module and in opposite directions, and consequently travel in a straight line with a constant velocity. In most velocity selectors the magnetic field is supplied by a pair of permanent magnets and the electric field is produced by a pair of parallel conductors, set apart by a distance  $d$ , where an electric potential difference  $V$  is applied. Even in the non-ideal case (conductor length and width not much larger than the distance  $d$ ) the electric field lines are parallel close the center of the conductor gap. The  $\mathbf{E} \times \mathbf{B}$  velocity selectors allow mass and charge state separation of ion beams. Charged particles passing through orthogonal electric (E) and magnetic (B) fields are deflected unless their velocity is given by the ratio  $E/B$ . One can also scan the mass spectrum of ions entering the filter by varying  $E$ .

Let us assume that all ions possess a kinetic energy  $K$ , obtained after being accelerated from rest by an electric potential  $V_0$ . When these ions enter the selector, only ions with a well-defined mass-to-charge ratio will be transmitted. The mass of these transmitted ions is

$$m = \frac{2KB^2d^2}{V^2} \quad (2)$$

Then a plot of the ions mass as a function of  $1/V^2$  is a straight line.

Another element very common in particle accelerators is the switching magnet, selecting the momentum of a particle. The deflection of ions in a perpendicular magnetic field is proportional to the particle momentum per unit charge. As the magnetic force is orthogonal to the particle velocity, the velocity module remains constant though its direction changes in response to the sideways deflecting force of the magnetic field. If the particle velocity is  $\mathbf{v}$  at right angles to  $\mathbf{B}$ , the particle will experiment a circular movement of radius  $R$  at constant speed. The

centripetal force  $mv^2/R$  is provided by the magnetic force.

$$qvB = \frac{mv^2}{R} \quad (3)$$

or, in terms of the particle's kinetic energy,

$$B = \sqrt{\frac{mK}{q^2 R}} \quad (4)$$

A plot of the square of the magnetic field as a function of  $mK/q^2$  should then be a straight line.



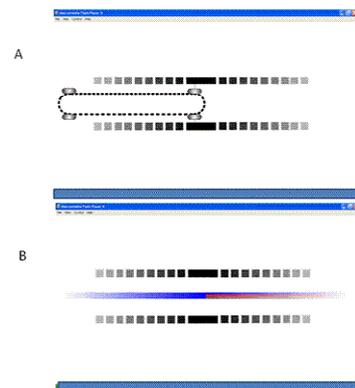
**FIGURE 1.** High-school student Arthur at the accelerator panel delivering a beam.

### Computer Simulations

In addition, the students also develop some computer-based activities, important to improve the understanding of the transport and the control of

charged particle beams which is mostly done by using lenses or a group of lenses. These lenses are found to be very important in accelerating charged particles in the accelerator in which transporting and controlling are essential for the beams impinging on the target. As it is well known from geometrical optics, optical lenses have a focusing action that maximizes the transmission of a light beam. Similarly, in the context of a charged particle beam, the lenses are elements that produce electrostatic or magnetic fields or a combination of both. More specifically, the students study the focal properties of an electrostatic lens. The computational simulations are carried out using the commercially available SIMION program [5]. The main advantage of using this software is that modeling can be easily performed avoiding analytical solutions.

Computers are also useful to visualize the working of a tandem accelerator. Figure 2 shows two outputs of a Flash program written for this end: (a) the generation of a high voltage in the tandem accelerator central terminal, done by the friction of a moving belt, and (b) the subsequent transport of a negative ion beam through this terminal, with partial conversion into neutral and positive beams.



**FIGURE 2.** Flash simulation illustrating the ion beam acceleration and stripping. A) The Pelletron chain charges the accelerator terminal shell. B) A negative beam is accelerated, and stripped at the terminal shell.

### SUMMARY

We reported a program developed by a Brazilian State Funding Agency (FAPERJ) for high-school pupils demonstrating interest in physics. The purpose is to bring the high-school students to the daily activities of researchers in universities. The authors believe that at the individual level, the program stimulates the

scientific formation of students and identifies new vocations in science. In addition, at a more general level, the program contributes to the dissemination of scientific knowledge, demystifying physics and articulating research and teaching. Up to the present moment, four students have participated in this program. The experiments, computing simulations and program writing carried out at UFRJ give the pupils a very good subsequent practice to the subjects they learn at the high-school.

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