Physics courses for non-physicists; what should (and should not) be done

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Abstract

Very often, physics becomes an insuperable obstacle to many students attending other sciences or engineering, who perceive physics more than as a nuisance than as a necessity. Sometimes these previously formed negative criteria are encouraged by contents with noticeably omissions and inadequate or inefficient approaches to the subject. Here we discuss some matters considered essential for the normal development of any basic course for non-physicists at university level, with the aim of contribute to a better acceptance and understanding of the subject. They have been extracted from the authors' experiences when teaching physics at university level for years in different countries and faculties such as engineering, biochemistry, pharmacia, foods, chemistry, agronomy and geography. In a condensed form, the mentioned topics are: a) it is important explain to the students the contents of the academic course, and why they must study those topics as a necessity of their specialty; b) the laws of physics work in both ways; c) physics is factual subject, and must be taught as such; d) do not forget the information about the role of models in physics and their reliability range as a limited image of real world; e) optimize the laboratory work (real, not virtual) and f) when explaining microscopic or very complex topics, make use of films or animations to help the student to form a satisfactory mental picture of the studied event, as a previous step to the analytic description.

Keywords: Physics, teaching, time efficiency, teaching aids, content of courses.

Resumen

Muy a menudo la física representa un escollo insuperable para muchos estudiantes de otras ciencias o ingenierías, que perciben la física más como una molestia que como una necesidad. Algunas veces esos criterios negativos, formados con anterioridad, se ven estimulados por contenidos con omisiones notables o un acercamiento a la asignatura inadecuado o ineficiente. Aquí se comentan algunos aspectos considerados esenciales para el desarrollo normal de cualquier curso básico para no físicos de nivel universitario, con el fin de favorecer una mejor aceptación y comprensión de la asignatura. Han sido extraídos de la experiencia de los autores al impartir física de nivel universitario durante años en diferentes países y facultades tales como ingeniería, bioquímica, farmacia, alimentos, química, agronomía y geografía. De forma condensada, los aspectos mencionados son: a) es importante explicar al estudiante el contenido del curso académico y el porqué se deben estudiar esos tópicos como una necesidad su especialidad; b) las leyes de la física funcionan en ambos sentidos; c) la física es una disciplina factual, y debe ser impartida como tal; d) no se debe olvidar la información sobre el papel de los modelos en la física y su rango de validez como representación parcial del mundo real; e) optimizar el trabajo de laboratorio (real, no virtual) y f) al explicar temas microscópicos o complejos, emplear films o animaciones para ayudar al estudiante a formar una imagen mental adecuada del evento estudiado como paso previo a la descripción analítica.

Palabras clave: Enseñanza de la física, eficiencia temporal, medios auxiliares, contenido de los cursos.

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I. INTRODUCTION

In meetings and congress about physics teaching is very common to find theoretical schemes about how to teach physics; however, is far less common to find solid arguments explaining why the given proposal is believed to be better than others [1, 2, 3, 4, 5, 6, 7, 8, 9]. Another distinctive feature of those schemes is that the time-efficiency problem is seldom mentioned. Assuming that the number of hours assigned to the course will not change, never becomes clear how the promoters would know if the students will learn more and better using the proposed scheme instead of another one. As a rule, reports comparing the results obtained in the particular group of students with others that follow different schemes are also missing, as well as the figures evaluating proficiency in tests, or the number of students successfully passing the course.

Quite less common is to find reports discussing what to teach instead of how to do it, which is a clear symptom that no much time is devoted to think about this particular problem; *i.e.*, which are the essential features that must be taught, and their connection with the specific matters the students will have to learn later on [10].

Another unreasonable thing you may find in connection with physics teaching, and not only in meetings and congress, but also in the planning of education policies, is that some people put all the stress on the pedagogic aspect of the problem, paying little attention to physics. It is very hard to accept that someone, without mastering the complexity of physics, could consider himself competent to state rules about how physics must be taught. The necessity to master basic physics for teach or devise policies on the subject is obvious to physicists, but do not seem to be for people trained in social sciences without physics studies at university level.

Without further mentioning the time-efficiency problem, which extends beyond the scope of this paper, yet with the aim of making the most of the available time, it seems appropriate to comment some experiences related to *what* to teach instead of *how* to do it. These comments are based on experiences collected in a long lapse of time, while teaching physics at university level in different countries and faculties in fields like engineering, biochemistry, biology, pharmacia, foods, chemistry, agronomy and geography.

Many students perceive physics as a nuisance instead of a necessity, and sometimes their previously formed negative criteria are encouraged by contents with noticeably omissions and inadequate or inefficient approaches to the subject. We feel that a good deal of these drawbacks could be overcome with little effort. To our minds, the following remarks could be helpful for easing the acceptance and understanding of physics when the main interest of the students is not focused on it. We hope these comments could have some positive impact in decreasing the academic failure in courses for non-physicists, where physics becomes too often an insuperable obstacle for many students.

II. ESSENTIAL FEATURES TO TAKE INTO ACCOUNT IN UNIVERSITY COURSES

Some features we have considered essential to improve the teacher's performance in any course of basic physics are the following.

1. The students should have information about what is expected from them at the end of the course and in any test (and the teacher what must expect from the students beforehand).
2. Physics laws works in both senses
3. Math and Physics and are different kind of sciences. Math is formal; Physics is factual, and must be taught as such.
4. Reality is more complex than any model.
5. Use laboratory works and demonstrations in an adequate form, avoiding defect or excess, beginning with the simpler ones.
6. Include films or moving pictures to assist the visualization of phenomena not accessible to direct observation.

1. The students should have information about what is expected from them at the end of the course and in any test (and the teacher what must expect from the students beforehand)

a) In the course

In many places is tradition to hand the students the content of the course at the beginning. In others, some explanation is given in class about the necessity of studying each particular topic, mentioning why these topics will be useful to them in the future. However, sometimes physics courses are not presented in a proper way for a number of reasons. The consequence is that the more concerned students repeatedly ask themselves, or to the teacher, why some particular topic must be studied and learned, because in their minds that topic have nothing to do with their specialty.

It seems important to avoid teaching a subject without the students having the least idea why the necessity of do it, and when and how will be useful in the future. That demands from the teacher a minimum knowledge about the students' specialty, which unfortunately sometimes is beyond the teacher's aim. The lack of information may become an important factor for holding back the student motivation for physics at a whole. This fact could also become one of the main factors differentiating 'good teachers' from 'bad teachers' from the students' point of view.

b) In the tests

At the end of each theme or logic unit, it is important for the students to have a clear idea what abilities are they supposed to show. That includes:

- *Which analytic expressions the students should memorize, and which not.*

There is some tendency in students, and in certain teachers, to give the same value to a fundamental law of physics and to a very particular analytic expression. Therefore, many students get lost at a sea of mathematical formulas, becoming very difficult for them to separate the main equations from the secondary ones. Also happens that there are teachers that prefer to test the secondary, asking for very particular details, under the assumptions that the students must know the important things -never emphasized in class-. This situation is somewhat connected to 'detail' or 'intelligence' questions, where the student must be able to introduce some additional data not directly related to physics. For instance, some geometric or trigonometric formula assumed to be known, without being previously mentioned or warned about in the course.

- *Advise the students about expecting theoretical questions in the tests.*

What do we consider a theoretical question? These are some examples.

a) Which are the validity limits of Newton's laws? Or of Hooke's law? (Or of any other law).

b) How you could change the kinetic energy of a moving charged particle by means of a static magnetic field? Give a brief explanation of your reasoning.

Nowadays there is a right tendency to add more theoretical or reasoning questions to tests -up to 50%-, and it becomes obvious that the student also needs some training for answering rightly this kind of questions. An example appears in figure 1, based on a free software that allow preparing groups of questions and other aids in an easy way (http://hotpot.uvic.ca/).

- *In class, incorporate notions about the complexity of the problems to be solved in tests.*

It is always possible to make some type of classification of the complexity of the typical problems showing up in physics courses. For instance:

1. Problems solved by simple substitution in a formula, finding the value of the unknown factor.
2. Those that need the use of two formulas.
   a. Belonging to the same topic.
   b. From different topics.
3. Those were three or more formulas are involved from the same or different topics.
4. Problems with the solution involving a simple differential equation, etc.

The students must always we aware of the mathematical features they must dominate: for instance, working with formulas, linear systems of equations, 2nd degree equation, analytic geometry, vector algebra and so on. The teacher must never wait for the test or examination to check if the students know some mathematical aspect not previously recalled in class, since it will lead to unnecessary fails.

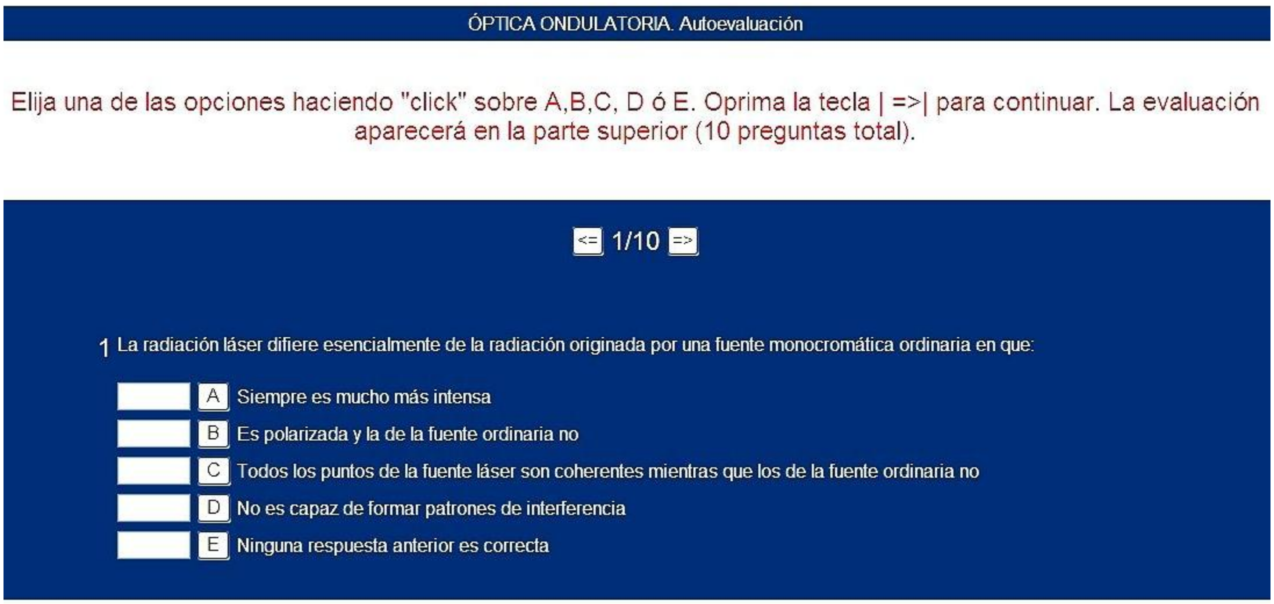

FIGURE 1. One page of a self-evaluation theoretical test including 90 similar pages, prepared using the free access software 'hotpot' (http://hotpot.uvic.ca/). This particular test is accessible in http://www.fisica.uh.cu/bibvirtual/fisica_aplicada/fisica1y2/index.html .

An important number of academic failures happen because the students do not have the necessary training to solve the mathematical part of the problems. Often they know the physics and are able to recognize, set and connect in the laws and equations involved, but no more. It is impossible for them to use the necessary mathematics for arrive at the solution. An additional problem comes from the fact that, as basic physics is usually taught in the first year of the specialty; the teacher has to confront the differences in the previous knowledge of the students arriving from different sites, both in physics and mathematics. This is clearly beyond the teacher's possibilities, since the learning process depends strongly on the previous history of the student. However, it will do no harms spending a little time reminding matters which are supposed to be known (but which very often are not).

2. Physics laws works in both senses

Students must be aware that physics laws work in both senses. There are teachers that analyze the laws only in the direct way, without ever mentioning inverse examples. However, later on in tests, introduce questions that must be answered reading the laws in the inverse way, contrary to the usual order of reasoning that the student is used to. In some way, they are also a type of a 'questions of intelligence'. Students must be also trained in these types of questions before arriving at the test, which should depend on knowledge, not on intelligence.

Example 1. The formula $W_R = \Delta E_c$ reads, from left to right, that a resultant or net force working on a particle must always cause a change in its kinetic energy. However, the inverse reasoning is seldom stressed: when the kinetic energy of a particle changes, it is *necessary* the existence of an acting force on it (and not any force, but a net one).

*Example 2***.** In many cases where the time allowed for the course is very limited (very common in basic physics courses) the second Newton's law is presented without emphasize previously the meaning of each parameter; *i.e.*, the concept of mass and its measurement, or the force concept, dynamometers, etc. It is not mentioned that is only valid in inertial reference frames, that must be applied exclusively to particles (or material points), and so on. To make the second law perceptive to the student, the questions in figure 2 should be always explained before presenting the law. Being Newton's laws the foundation of any subsequent topic of mechanic, a poor knowledge about these laws will be undoubtedly a huge drawback for any common student.

Sometimes it is also omitted the explanation that the vector character of forces do not come from mathematical deductions, but from their physical properties, with an empiric nature. It is common to find much confusion about this topic, because the students take first the mathematical information, and nobody tells them that this kind of mathematics came after the study of the physical properties of forces.

3. Math and Physics are different kind of sciences. Math is formal; Physics is factual, and must be taught as such

In the drawing of figure 3, we show some areas of the human knowledge belonging to the *fields of investigation,* following the classification of Mario Bunge‡ [11]. Other areas of knowledge belong to the *fields of beliefs* (*i.e*., theology, politic ideologies). The formal-logic approach of Mathematics must not be confused with the factual-empiric of Physics. Math are deductive, and do not need the experiment nor the interaction with reality, while factual sciences describe the laws governing different real events or processes; they are empiric sciences and need the continuous interaction with the external world (see ref [3]).

However sometimes when teaching physics, the emphasis is directed towards the formal deductions and mathematical training, given very little weight, or none at all, to the factual aspects. Physics has to do with the reasoning to understand and explain the laws ruling the real world. It has to do with how to find and describe the cause-effect connections between different phenomena by means of exact -or near so- analytic expression, both in quality and quantity. It has nothing to do with stating formulas without knowing where they came from, and solving them as some any other pure mathematical problem. That is not physics, at least not of university level.

Another ill conception about the teaching problem in physics is, to our mind, to postulate the theory for later enlighten it with the description of some experiment. This order of things do not show the way science really works, because the reasoning is reversed. Laws come from a long induction process, involving hundreds or thousands experiments carried out from many people; they are not deduced, but induced. To state the laws of physics as a postulate, with the aim of justify them later with some experiment, is contrary to the way that the laws in any science are revealed by means of the scientific method.

Observation and experiment come before than theory. That is the reason why we think that the correct order for presenting any topic in physics should be as follows:

a) Description of the event or outcome and/or experiments on the matter.

b) Scientific explanation (theory, laws)

c) Confirmation of the theory.

A typical example, suitably presented in most textbooks, is the photoelectric effect. In this order usually appear:

- A description of the effect and the experiments with the photoelectric cell, showing the contradictions with the previously known wave model.
- The photon as a postulate and the corresponding Einstein equation.
- Verification that these equations adjust to the experimental data in quality and quantity.

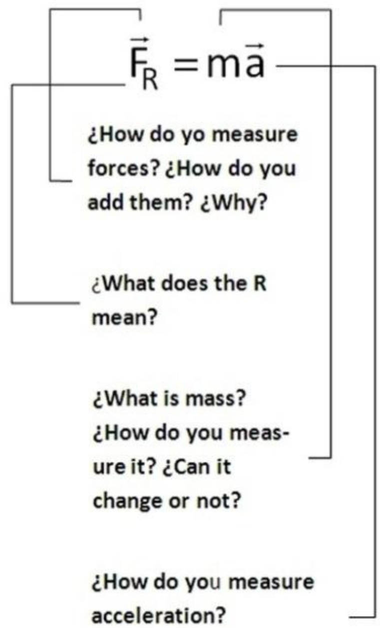

FIGURE 2. Additional matters to discuss about the second law are that the dimensions of the body cannot be taken into account (concept of particle) and that is only valid in an inertial frame of reference.

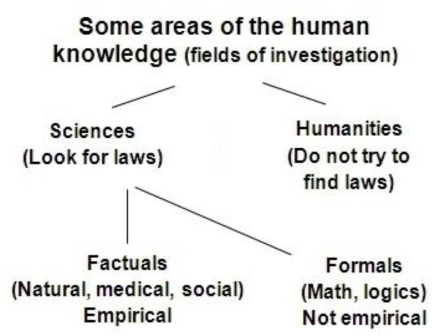

FIGURE 3. Some areas of the human knowledge; other areas belong to the *fields of beliefs*.

4. Reality is more complex than any model

It is important to tell the student that Physics refers to approximations of reality (models). The range of validity of

‡ Argentinian-canadian physicist and philosopher. Prince of Asturias prize in 1982 and 16 doctor honoris cause degrees. http://es.wikipedia.org/wiki/Mario_Bunge#Libros_de_Mario_Bunge_en_espa.C3.B1ol)

the model should be stressed to avoid wrong results when trying to apply the model in cases where cannot be valid.

Example. In many basic courses, due to the time factor, the topic 'System of Particles' is poorly considered or not considered at all. The proof that, concerning translation, the center of mass behaves as if all mass were concentrated in it, is absent.

When considering the center of mass (without mass changes) the second law keeps his form, but changes its meaning.

$$\mathbf{F}_{\text{Rext}}=\mathbf{M}\mathbf{a}_{\text{CM}}\ ,$$

M is now the mass of the whole system, and F refers only to forces external to the system, since the sum of all internal forces becomes null due to the third Newton's law. The particles of the considered system may be united, as in a rigid body, or disperse as in a gas. The existence of the center of mass in the strict justification for the model of particle introduced at the beginning of physic courses (figure 4).

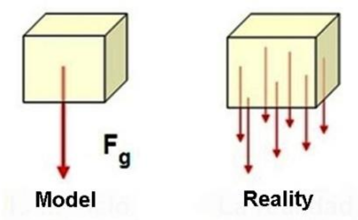

FIGURE 4. A very common and simple model. The mass is assumed condensed at the center of the body. It only can be done in situations where the size of the body, its rotation state or vibrations does not affect the results of the analysis.

5. Use laboratory works and demonstrations in an adequate form (avoiding defect or excess, beginning with the simpler ones)

Advances in informatics have led some people to think the possibility of substitute experiments and measurements with a computer and software representing them. The handling, regulation and adjustment of any instrument in the lab, even the very simple ones, has nothing to do with pressing keys on a keyboard. The use of hands, the interaction of muscles and the sense of touch, smell, hearing, the tridimensional vision of the object and the instruments, all together, provides a way of learning very different to that of watching a screen. The message arrives to the brain in a very different way, and the collected experiences are others; it is not necessary to be a psychologist to reach this conclusion. That are the reasons why, beginning at the first grades, laboratory work is essential, not only in physics, but in any factual science.

Without rejecting informatics as an additional tool for teaching, it is clear enough that pressing keys or watching movies has nothing to do with the experiences gained when handling real objects. There is no difference between leave out experimental works than in totally substitute them with virtual resources.

In laboratory work, or maybe in class, the operational criteria for the definitions of the fundamental magnitudes should at least be mentioned. Very often this topic is avoided, and the student remains in the dark about how the fundamental magnitudes are defined (time, length, temperature, and so on). Sometimes this leads to students (and sometimes to teachers) to a mental closed loop, trying to define them from other equations, as if magnitudes were words in a dictionary, which are clearly not.

As an additional suggestion, in basic courses it seems essential to make emphasis in direct measurements before than in indirect ones. The first are those which depend on some instrument to get the value of the measured magnitude in a single step (mass, force, time, length). An indirect measurement is that acquired with the help of some analytic expression (energy, moment of inertia, angular moment).

6. Include films or moving pictures to assist the visualization of phenomena not accessible to direct observation

There are many microscopic phenomena where is not possible (or quite difficult) to show a direct observation of the studied event. Examples are a longitudinal wave, the molecular movement in a gas or the electromagnetic wave. Here it becomes important to show the student some image to facilitate the mental picture of the phenomenon talked about.

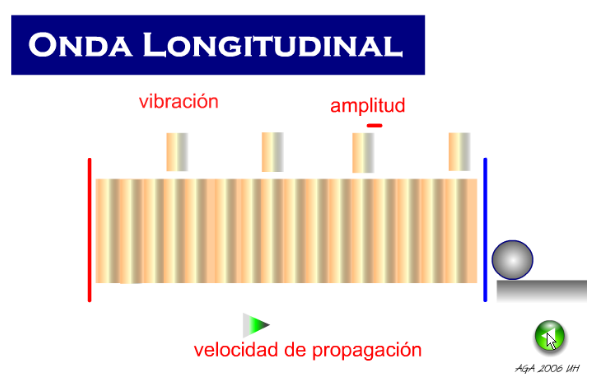

FIGURE 5. Snapshot from a moving picture depicting a longitudinal wave. Downloaded from http://www.fisica.uh.cu/bibvirtual/fisica_aplicada/fisica1y2/animaciones.htm

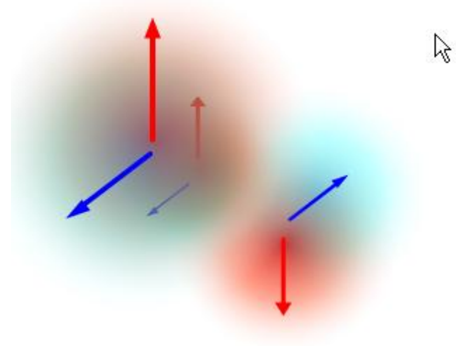

FIGURE 6. Snapshot from a moving picture representing the propagation of a monochromatic and polarized electromagnetic wave. Downloaded from http://www.fisica.uh.cu/bibvirtual/vida%20y%20tierra/radiacion%20y%20vida/index.htm.

We are not suggesting the abuse in using pictures or movies either, since usually time is limited enough to spend it in secondary matters, neither the substitution of the necessary analytic description with these aids. We are stressing the importance for the student in having a right mental picture of the phenomenon (something very difficult for some people) before carrying out the mathematics treatment. It is attributed to Einstein the saying that first you must understand the phenomenon and that formulas came later on. Some examples of moving animations appear in figures 5 and 6 (in Spanish).

III. CONCLUSIONS

To our mind, some unavoidable aspects to take into account when teaching basic physics, above all in non-physics university specialties, are the following: a) tell the students the course contents and explain it; b) laws of physics work in both senses; c) physics is a factual subject; do not forget it; d) stress the information about models and their range of use; e) Optimize the laboratory work (real, not virtual) and d) Make use of films or moving pictures whenever necessary, and no more.

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